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# EYE STUDIES

A

# SERIES OF LESSONS ON VISION

AND

# VISUAL TESTS

BY

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"The light of the Body is the Eye."—*Christ*

"Methought, all his senses were locked in his eye, as jewels in crystal."
—*Shakespeare*

CHICAGO
J. M. JOHNSTON
1892

TO MY MOTHER,

WHOSE SPIRITUAL FACE AND SPECTACLED VISAGE HAVE BEEN BEFORE ME SINCE EARLY CHILDHOOD AND STILL ABIDE A LIVING PRESENCE AND INSPIRATION,—

TO THE GROWING THOUSANDS OF STUDENTS AND PRACTITIONERS IN OPTICS, WHOSE HIGH VOCATION IS BUT JUST BEGINNING TO BE APPRECIATED,—

TO THE MANY WHOSE EYES HAVE BEEN CORRECTLY FITTED, AND THE MANY MORE WHOSE SIGHT HAS BEEN INJURED BY INEXCUSABLE IGNORANCE AND MISFITS,—

TO ALL THESE THIS VOLUME IS DEDICATED, WITH THE HOPE THAT THEIR EXPERIENCE IN THE THINGS OF VISION MAY PROVE AN INCREASING DELIGHT TILL THE DAWN OF AN ETERNAL MORNING, WHEN WE SHALL BEGIN TO SEE AS WE ARE SEEN,

BY THE AUTHOR.

# PREFACE.

WE first prepared and published our Eye Studies serially, in the *Johnston Eye Echo*, an optical journal edited by the author. With some exceptions, to be noted farther on, the contents of the Eye Study series, as now presented, appeared during the five years' continuance of the *Echo* from 1885 to 1891.

The article on Color-Blindness we prepared first for the *Eye Light*, the *Echo's* successor, of which the author was, also, editor, during 1891. The lesson on Strabismus has been considerably expanded. The series has been entirely revised and enlarged.

Those who read these lessons in serial form will notice a marked change in their character as now combined. Each topic, as here presented, is treated in a single lesson. As then treated, the same topic was frequently continued in several lessons, the subject being too large to be completed in a single issue. As a result we had twenty-eight lessons in the paper. Covering each separate subject with a single lesson, we have in the book only fourteen lessons, including the new one on Color-Blindness. Everything of value in the serial discussion has been retained, and an expansion of many points indulged in to promote greater clearness and explicitness.

Where repetitions occur it is believed they will be found to result from a principle important in the preparation of a book having text-book qualities. This requires that where two phases of a subject meet and interlap, the discussion shall be conducted, in turn, from both standpoints, permitting a survey of the same field with a varied perspective. An illustration is furnished in the discussion of Hypermetropia and Myopia. Like

most subjects, they are best understood by comparison —in this case, the comparison of contrast. Discussing Hypermetropia, we define and describe. Reaching the standpoint of Myopia, we resort to comparison, which involves incidental but necessary repetitions touching the nature of Hypermetropia,— repetitions which set each defect in clearer light.

That this method will be regarded as an excellence the author believes. Perhaps this is the place to confess that variation from this general method by some recognized authorities has been the chief secret and source of awakening our interest in developing optics. A frequent complaint has reached us that writers treat each topic in a disjointed, fragmentary way, scattering different phases of its treatment through their books so indiscriminately as to make the looking up and gathering together, necessary to secure a completed conception of the subject, a tedious process. Our treatment takes an entire survey of each subject in the one lesson assigned it. Whenever two lessons have mutual relations this method necessarily leads to a measure of repetition. Apparently the most of the commendations given our lessons have been prompted because of the above method in their development. When the mind moves logically, it takes in a subject in all its relations,— there is a natural unfolding of the theme, a progress of thought and breadth of view, combining unity and comprehensiveness. There is the absence of one-sidedness, fragmentariness. All minds are naturally logical,—not that all can develop a subject logically, but that all recognize the value of logical development. Perceptively, if not constructively, they are logical. Conscious of his lack of limpid rhetoric and a facile pen, the author may be pardoned the single gratulation above indulged and credit to his constructive conception, his methods of classification, the hearty appreciation he has received and the numerous solicitations that the Eye Studies be published in book form.

We cannot forbear brief reference to encouraging progress in optical literature in the last few years. There was painful need of it. The great work of Donders was not written till 1864. Most of the other works mentioned below have been written in the present decade, the chiefest among them within from three to six years. Considering the importance of the subject this is astonishing. But it is less astonishing than another fact,—the dearth of exclusively optical periodicals. To the best of the writer's knowledge and belief he was the editor of the first journal of exclusively optical character. Its initial number appeared in Detroit for January-February, 1886.

Early in 1881 the editor had considered and proposed such a journal. For various reasons the project was deferred until 1886. The next purely optical journal of which we have knowledge was started in Chicago in the summer of 1886. Its career was brief. In 1891, optical journals were started respectively in London and New York, both called the *Optician*. At the time the *Eye Echo* was first issued the discussion of optics in the jewelers' journals was so meagre as to receive but slight recognition. Now these journals, of which there are many of excellent quality, keep under pay a regular oculist or expert optician to conduct an optical department. The increased attention given the matter during the last few years is something noteworthy,—a fact full of inspiration to those who appreciate the important relation of optics to civilization.

With grateful recognition the writer makes acknowledgment of his indebtedness to those whose works he has consulted, chief among whom he would mention Donders, Landolt, Mittendorf, Stevens, Juler, Carter, Bohne, Valk, Giraud-Toulon, &c., &c.

J. M. Johnston.

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# INTRODUCTION.

VISION is the noblest of man's senses. Imperial sweep and swiftness of glance and minute delicacy of construction make it a marvel of infinite skill.

The humblest position among the senses is occupied by taste. Essential as is its office, its ministrations are devoted primarily to the body. The fireman that feeds the engine of the physical system is the palate.

A step above this we find the sense of feeling. The nerves of sensation are its fingers. Through them is fulfilled its function of handling and fashioning the mere materials of civilization. Its touch transforms their rough exteriors till they glow with a perfect luster.

A step higher is the sense of smell. That delicate discernment, by which it distinguishes between noxious and wholesome odors, renders its ministry to civilization invaluable. Standing midway between the lower and the higher couplets of the senses, its duties are divided, perhaps about equally, between ministering to the physical and the æsthetic in man.

Taking a fourth step brings us to a power still nobler, the "hearing ear," for the higher the physical sense the more largely does it minister to the mental nature. While hearing serves the other senses with patient fidelity, its chief charm is that it waits upon the soul with a "sweet concord of sounds." "Sound is a perception of the soul."

We now step to the highest physical plane and stand face to face with the sense of sight. It presides over the activities of these lower faculties and transcends them in the reach of its power. There is a hint of its supreme position in the naturalness with which we speak of sight as an agency for discriminating facts which are really

learned through other senses. For example, we say, I see that the sound is melodious, the flower fragrant, the surface smooth, the flavor agreeable. Vision is regarded worthy to represent even the operations of the mind. When a matter becomes clear to the judgment or understanding we say, "I see, I see the point; I see the principle."

The supremacy of vision may be seen in the following series of contrasts. The palate can make no report as to taste till the flavored substance *passes within* the lips. The sense of feeling can say nothing of an object till the latter *touches* the nerves of sensation. The nostril can discern the source of an odor only at a distance compara tively *short*. The ear can report upon the cause of a sound at a distance somewhat greater, and yet within limits *really narrow*. But the eye can *sweep across measureless space* and report the location of a fixed star. This pre-eminence of the visual sense enthrones it among the physical faculties and adds fresh emphasis to the already emphatic adage, "know thyself."

Other reasons, some of an urgent nature, render the eye an attractive and deserving subject of study. No one is without a personal interest in the matter whether conscious of it or not. If not necessary in youth, optical treatment is sure to be needed by the eye sooner or later, unless death closes it in early life. As age advances a gradual change in its structure invariably takes place. This change, involving loss in the power of perception, necessitates compensating aid. Lenses properly ground and adjusted replace this loss, thereby making themselves necessary factors in an enlightened civilization. We *could* do without them, and so we could also dispense with books and schools. Savages do.

This change in the eye, produced by age, naturally makes every person a present or prospective customer of the optician. Properly instructed, each one comes to

realize the danger of postponing the fitting of his eyes until sight has become impaired; or of neglecting, if he already wears glasses, to have his eyes regularly re-fitted as advancing years gradually modify their structure. What one wears or expects to wear, can hardly fail of interest to him. This dependence of vision, and even of civilization, upon the glasses of opticians should certainly stimulate them to patient thought upon optical studies.

This line of thought is vastly significant when we remember that in addition to the above structural change, to which every eye is subject, even if normal, there are also abnormal structural conditions affecting the vision of a large proportion of people. These conditions are usually inherited or developed in early life, and so need the early attention of an optician or oculist.

Children as well as adults may have a tendency to push the book away an unnatural distance, or may hold it too close to the eye, or look askant at it, or sidewise, or see double, or differently out of the two eyes; similar objects may look unlike, round objects, oblong, straight lines, irregular, and *vice versa;* nervous, muscular or other affections may develop cross eye, and weak, fitful or painfnl vision, especially in artificial light. These and other symptoms, with their respective optical treatment, should, as a matter of course, become thoroughly familiar to the optician, and to some good extent through him to the community, that those suffering in vision may learn to seek suitable aid and do so promptly. It is the ambition of these Eye Studies to promote this end by disseminating needed information.

THE AUTHOR.

## ERRATA:

Page 20—Angle of incidence and refraction should read angle of incidence and *reflection.*

Page 34—Third line from top should read No. *14* lens instead of No. 7.

" Fourth line from top should read *fourteen* inch focus instead of seven inch.

" Seventh line from top should read No. *14* instead of No. 7, and 7 instead of 3½.

Page 48—Oculi uno should read oculi *unati.*

# EYE STUDIES.

## LESSON I.

### Constituents of Vision.

*Eyeball.*—In form the eye is a globe whose average diameter in the adult is about seven-eighths of an inch. For convenience in locating any point or region of the eye, optical usage regards it, like the earth, as encircled midway between its poles with an imaginary line called its equator; as having its poles connected by another line known as its optic axis, one end of which is situated in the front of the eye, at the center of the cornea, called the anterior pole, the corresponding point in the rear being the posterior pole; as divided by the plane of its equator into anterior and posterior hemispheres, by the plane of its horizontal meridian into upper and lower, and by the plane of its perpendicular, into nasal and temporal hemispheres; as cut into eight quadrants by the planes of its perpendicular and horizontal meridians intersecting the plane of its equator and each other; and, as encircled by other meridians whose planes stand at the various angles or degrees into which its surface is divided.

*Muscles of Rotation.*—The eyeball is supported in its orbital cavity, within a cushion of tissue and fat, by six muscles, four of which are known as the *recti* and two as the *oblique*. The recti muscles have their origin in the rear of the orbital cavity. They embrace the eyeball and extend forward to within about a quarter of an inch of the cornea, and are located as follows: the *superior rectus* above the eye, the *inferior* below, the *internal* on the nasal and the *external* on the temporal side. The oblique muscles, called respectively *superior oblique* and *inferior*

*oblique*, are located on the inner or nasal side of the orbital cavity, one above the other, as the words descriptive of them indicate. By the expression, Muscles of Rotation, we designate the six muscles mentioned above. Their office is to rotate the eye in any direction, at any angle. The point about which they act is called the centre of rotatation. The eyes' celerity and variety of movement are due to the vigor of these muscles. Their highest service is to converge the two eyes sufficiently to read and see objects close by. This movement, called convergence, is executed by the internal recti.

*Lids and Lashes.*—Guarded on every side by the frontal, nasal and cheek bones, the eye is still farther protected by lids and lashes. The latter protect from dust and insects; the former shield and curtain it, besides bathing it with tears secreted by the lachrymal glands. The corners of the eye where upper and lower lids join are the *canthi*, so called. The one next to the nose is called the *inner canthus;* the one next to the temple is called the *outer canthus.*

*Primary Elements of Vision.*—The elements of vision naturally divide into two classes, *primary and secondary.* The primary are fundamental to the act of seeing; the secondary are their necessary associates and supports. The only external or foreign element is light; the other constituents are ocular, being within the eye.

The primary elements group themselves under three heads: Rays of Light, Refracting Media, Reflecting Media. Each of these subjects will require a separate lesson. We pause here for only a word or two of description.

Light is an agent received directly or by reflection, from a luminous object. It is the first condition of vision.

The Refracting Media consist of the *cornea*, which is set in the front of the eye something like a crystal over

the face of a watch; the *aqueous humor* occupying the cornea's concavity, which latter is divided by the iris into two chambers, anterior and posterior, between which the humor freely moves; the *crystalline lens*, which comes next in order; and lastly, the *vitreous humor*, which occupies the large cavity in the rear of the eye. The cornea and crystalline lens are solids and transparent; the latter is also elastic in its normal condition. The aqueous and vitreous humors are fluids and also transparent. In passing through these four refracting media the rays of light are bent in their course, the same as in passing through air, water, glass or other transparent substances. Their function in the production of vision will be fully discussed in a subsequent lesson.

Among the Reflecting Media the element of chief importance is the *retina*, a nervous membrane of extreme sensitiveness lining the posterior portion of the vitreous cavity. Upon it are formed, in the act of perception, images of the objects perceived. It is not equally sensitive in all parts. The point of greatest sensitiveness is known as the yellow spot (*macula lutea*). That the object may be clearly visible the image needs to be well defined and distinct, and therefore it must fall upon this spot. Any conditions which throw it upon any other point render vision more or less dim and imperfect. The *optic nerve*, of which the retina is an expansion, extends back through the coats of the eye to the brain. By it the impression or image reflected upon the retina is also transmitted to, or in some mysterious way reflected through nerve and brain upon the perceptive power of the mind. When the conditions are such as to throw the image upon the opening through which the optic nerve enters the eye no perception can result. This point, in consequence, is called the *blind spot* (*poras opticus*).

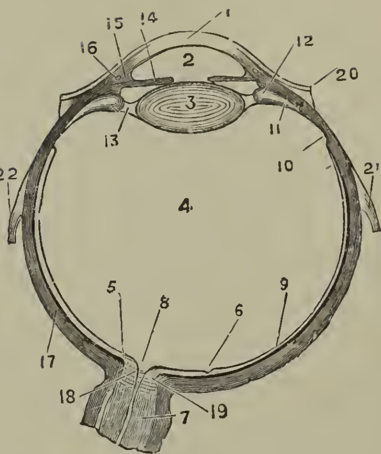


Fig. 1.—Horizontal Section of the Right Eye.

| | | |
|---|---|---|
| Refracting Media, | 1. | Cornea. |
| | 2. | Aqueous Humor. |
| | 3 | Crystalline Lens. |
| | 4. | Vitreous Humor. |
| Reflecting Media, | 5. | Retina. |
| | 6. | Yellow Spot. |
| | 7. | Optic Nerve. |
| | 8. | Blind Spot. |
| Choroid Region, | 9. | Choroid. |
| | 10. | Ora Serrata. |
| Ciliary Region, | 11. | Ciliary Processes. |
| | 12. | Ciliary Muscle. |
| | 13. | Suspensory Ligament. |
| | 14. | Iris. |
| | 15. | Ciliary Ligament. |
| | 16. | Schlemm's Canal. |
| Sclerotic and Adjuncts, | 17. | Sclerotic. |
| | 18. | Sclerotic Foramen. |
| | 19. | Lamina Cribrosa. |
| | 20. | Conjunctiva. |
| | 21. | External Rectus. |
| | 22. | Internal Rectus. |

*Secondary Elements of Vision.*— The secondary elements may be grouped under the following heads: *Eyeball, Muscles of Rotation, Lids and Lashes, Choroid and Ciliary Regions, Sclerotic, Conjunctiva.*

The first three of these attract immediate attention as you approach the study of the eye, and so we considered them at the beginning of the lesson. We next glanced briefly at the primary elements of vision, and now conclude the lesson by considering the last three of these secondary elements.

*Choroid and Ciliary Regions.*— Immediately behind the retina is the choroid coat. It is a dark vascular membrane surrounding the vitreous cavity and absorbing light not utilized in the act of seeing. It also furnishes nutrition to the eye, particularly to the vitreous humor and crystalline lens. As it extends forward it expands into the several members of what is known as the ciliary region. The point where the expansion begins is called the *ora serrata*. Anteriorly to this the choroid is developed into the ciliary body consisting of some seventy folds or plaits constituting the ciliary processes. On their surface is situated the ciliary muscle, or muscle of accommodation. The suspensory ligament (zone of Zinn) consists of a capsule of transparent tissue uniting the crystalline lens to the ciliary processes, by which the former is supported, and through which the ciliary muscle modifies the refractive power of the eye. The way in which the ciliary muscle controls the convexity and consequent refraction of the crystalline lens is not perfectly understood. Most authorities accept the supposition of Helmholtz that the contraction of the muscle relaxes the suspensory ligament, thereby leaving the somewhat elastic lens free to resume its naturally more convex shape, which increases its refractive power. The expansion of the muscle, on the contrary, contracts the

ligament, producing, thereby, the opposite effect, a flattening of the lens, which diminishes its refractive power. On the authority of Merkel & Gerlach, Landolt states that "the zone of Zinn is not a membrane, as is sometimes said, but an agglomeration of fibres having the nature of connective tissue." The *iris* is a circular curtain, variously colored in different persons, and suspended before the lens from the front of the ciliary processes. It is perforated through the center to admit the light. Involuntary muscular fibres encircle this perforation or pupil; other fibres radiate from it. By the radiating fibres it is enlarged or dilated to admit more light; the circular fibres contract it when less light is needed. The ciliary ligament is a ring of fibres uniting the iris, cornea and sclerotic. A small orifice through its center, called Schlemm's canal, carries veins and lymph.

*Sclerotic.*—The sclerotic is the external coat or tunic of the eye, and covers about seven-eighths of its surface, the cornea covering the remaining one-eighth. In the front it is known as the white of the eye. The opening in it, through which the optic nerve reaches the brain, is called the sclerotic foramen, across which is suspended the lamina cribrosa. This latter consists of a fine network of fibrous tissue through whose meshes the optic nerve fibres and vessels find exit.

*Conjunctiva.*—A thin, transparent membrane, called the *conjunctiva*, loosely attached to the sclerotic, forms a lining to the inner side of the lids. From them it is reflected over the entire front of the eye. Being of a mucous nature, and secreting a portion of the fluid which moistens the eye, it promotes the free movement of lids and eyeball.

To comprehend in a word the chief work of the eye, consider the secondary elements of vision all in normal condition, fulfilling their respective functions, the lids

opening and admitting the rays of light reflected from an illuminated object. In their course through the refracting media these rays are converged to numberless focal points upon the retina. A diminutive image of the object is thus formed upon it. This image is reflected not only forward from the retina, but in some manner backward through the nerve to the brain, by the combined efforts of what we have denominated the reflecting media. By its perceptive power the mind grasps this image, and through it, the object perceived. This is seeing.

## LESSON II.

### Rays of Light.

*Radiation of Light.*—An imponderable medium called ether is supposed to be everywhere present, extending throughout occupied as well as vacant space, permeating solid and liquid bodies alike. Undulations of ether, set in motion by chemical causes, produce, through the eye, the sensation of light, as vibrations of atmosphere create, through the ear, the sensation of sound. Apart from the eye what we call light is simply ether vibrations. These striking the nerves of the retina is what gives the sense of illumination. A similar effect may be produced, even while the eyes are closed, by a stroke upon the eyeball or a shock to the ocular nerves. Illustrations of this are familiar to children, who describe the sensation as "seeing stars."

Light is projected, primarily, from bodies rendered self-luminous by certain chemical changes, and secondarily, from objects reflecting it. Every surface projecting either direct or reflected light is covered by an infinite number of illuminated points called radiants. From each radiant point numberless lines of light shoot out in every possible direction. Each of these lines is called a ray. The collection of lines projected by each radiant is called a pencil. The rays of each pencil in nature diverge. In their divergence the numberless rays projected by adjacent radiants intersect each other at an infinite number of points. Every point of space within their range is thus filled by innumerable rays and intersections of rays. One who seeks to understand the radiation of light must consider this fact. Otherwise the diagrams used to illustrate radiation are liable to lead him to suppose that illuminated points are centers, respectively

of only a few converging and diverging rays, whereas each one is the center of an infinite number. A few lines in each diagram are all that it is practicable to employ; but these are to be regarded as illustrating the course of an infinite number of rays similarly situated. In nature, as just stated, the rays proceeding from each radiant start off in divergent directions. But these directions may be changed by artificial means. Any refractive medium placed in their path will alter the course of the rays. If it has just the right convergent power it will change them from diverging to parallel rays. An increase of the same power will change them into converging rays. Parallel rays constitute cylindrical pencils. They are usually known as beams of light, and may be produced, as a matter of course, from convergent as well as divergent rays. As is obvious, media of converse refractive powers produce upon the same rays effects of converse character. Pencils of light, as we see, are divided into three kinds, *divergent*, *convergent*, and *cylindrical* or *parallel*. Parallel rays occupy a conspicuous place in both the theory and practice of optics. The optician's ocular tests are largely dependent upon them, particularly when determining whether or not the eye has any malformation. Parallel rays are employed also in determining the refractive power of a lens. The number used to show its refraction indicates the distance from the lens at which parallel rays form a focus, known as the principal focus. Rays are not only made parallel artificially, but even in nature they are in one instance parallel instead of divergent, viz., when reaching us from an infinite distance. That two adjacent rays from a heavenly body may be close enough together for both to enter the eye at once it is evident their divergence must, at starting, be hardly perceptible,— so slight in fact as to make them practically parallel: starting from an infinite distance they would therefore be actually so, of course. And at any distance beyond about twenty

feet, the rays entering the eye are parallel enough for practical purposes. Accordingly this distance is in common use in measuring the eye's refraction. Since the refraction of parallel rays is employed to discover whether the eye is of normal or abnormal structure and also to determine the distance of the principal focus of a lens so as to show us its refractive power, it is obvious that the principle involved should be clearly understood. Special attention is given it in the next lesson.

*Intensity of Light.*—The more numerous the rays falling upon a given surface the brighter its illumination. The farther this surface is from the source of light the fewer the number of rays falling upon it, because of their natural divergence, and the less, in consequence, its illumination. The law is that the illumination diminishes as the square of the distance increases. For example, suppose a given surface placed one foot from a certain source of illumination, it will, if removed two feet, receive only one-quarter as much light, and if removed three feet, one-ninth as much, and so on. Or, stated otherwise, the degree of divergence, in nature, is such that the rays falling upon a surface two feet distant, cover four times as much space as at one foot distant, and three feet distant nine times as much space, and four feet distant sixteen times as much space, and so on. In dim vision the reading is instinctively brought nearer the light and the eye to increase the intensity of the former by throwing into the latter a greater number of rays. In ocular affections which reduce the power of vision, notably cataract, a strong convex lens, called, because of its customary use, a cataract lens, may accomplish this result by enabling the patient to bring the object closer to the eye, thereby producing artificial near-sightedness.

*Reflection.*—Rays of light proceed upon straight lines until deflected by some refracting or reflecting medium, or until absorbed. Opaque bodies absorb or quench a portion of the light falling upon them. Smooth surfaces reflect it regularly in obedience to specific laws. All bodies, to a greater or less extent, disperse it. Dispersion is the irregular or scattered reflection of light from the numberless little facets constituting every surface. Even polished mineral and metallic surfaces reveal, under the microscope, innumerable small planes at all possible angles of inclination to each other. Lying at varied angles these facets scatter light in all directions. It is undesirable and impossible to polish them down till the surface is absolutely smooth. Without the property of dispersion objects would not be visible. An object absorbing all light would be invisibly dark. A surface in the sunshine reflecting all or even most of the light falling upon it becomes dazzlingly if not invisibly bright.

The term *dispersion* is more frequently used to indicate the separation into different colors which rays may undergo in the process of refraction. To avoid confusion of thought it would be well to distinguish between the two effects by the respective expressions, *reflective dispersion* and *refractive dispersion.*

*Definitions.*—Attention to a few terms will prepare for intelligible statements of the laws of reflection and refraction. A line perpendicular to a plane surface is called its *normal.* An *incident ray* is one impinging upon a plane surface; a *reflected ray* is one thrown back by a reflecting surface. The angle between the incident ray and the normal is called the *angle of incidence;* the one between the reflected ray and the normal, the *angle of reflection.* When the incident ray falls perpendicularly upon the surface it is reflected backward along the line of its approach. In this single instance the path of the

reflected ray coincides with that of the incident ray. In all other instances these rays stand apart, inclining to the surface obliquely from different directions, and forming equal angles with it. Two laws of importance may be noted here. (1.) The angles of incidence and refraction are equal, and both lie in the same plane with the normal. (2.) The principles applicable to a plane surface may be applied to a curved surface, also, by drawing a line tangent to the curved surface, at the point of incidence in the impinging ray.

*Refraction.*—When a ray passes out of one transparent medium into another of different density, as from air into water or glass, or *vice versa*, it is refracted or bent, provided it strikes the surface of the second medium obliquely. All rays striking a surface perpendicularly continue through the medium in the same direction. All oblique rays being refracted at the first surface of the medium continue through it in a changed direction. At the second surface if they strike obliquely again they are refracted again, and if they emerge into the medium from which they originally passed they resume their original direction, provided the two surfaces are parallel. When the two surfaces are not parallel the rays are refracted from their original direction toward the thickest part of the refracting medium. The first important principle of refraction is, that in passing from rarer to denser media, as, for example, from ether to air, or from air to water, or from either to glass, an oblique ray is refracted *toward* the normal. Conversely, when passing from denser to rarer media an oblique ray is refracted *from* the normal. Thus, changes of media involve refractive changes in the ray, except when it constitutes a normal or passes through media of equal density. In these two cases it continues unchanged in direction. Under one condition a reflective instead of a refractive change takes place which is explained in a subsequent paragraph under *total reflection.*

*Index of Refraction.*—We have seen that the incident ray and the normal constitute the angle of incidence, while the reflected ray and the normal constitute the angle of reflection. In like manner the angle between the refracted ray and the normal, or normal continued, constitutes the angle of refraction. In passing from rarer to denser media the angle of incidence is larger, as a rule, than the angle of refraction. In passing in the opposite direction the reverse is true, for when a ray passes backwards it retraces its path. While the media remain the same, this difference in size between the angles of incidence and refraction continues invariable. Whenever the media are changed there arises a new difference or ratio between these angles. When the ray is passed through a given medium *from vacuum* this difference between the angles of incidence and refraction constitutes a constant quantity known as the *index of refraction* of said medium. The index of refraction is sometimes determined by passing the ray from atmospheric air instead of from vacuum. In strictness, however, the former is the correct method. But the difference between the results obtained by the two methods is slight; the latter is more convenient and so is more common. This index is not itself the refractive power of the given medium, but it furnishes the basis for determining that power, and so is an important quantity. Though the principles of trigonometry are involved in calculating the index of refraction, we hope to make the subject satisfactorily clear by figure 2 and the following explanations.

In figure 2 let AB be the surface of water, HC normal to it, DC an incident ray and CE the refracted ray, refracted at the point C. If from the point of refraction C we take points equi-distant on the incident and refracted rays respectively, viz.: D and E, (the circumference of a circle having its center at the point of refraction will pass through equi-distant points) and if from each point

we draw a line perpendicular to the normal we shall have the lines D F and E G. These lines are called the sines of their respective angles, and their relation to each other shows the relation of their angles. That is, the angle DCH is to ECJ as DF is to EG. Accordingly the index of refraction, seeing it is equal to the angle of incidence divided by the angle of refraction, may be found by dividing the sine DF by the sine EG. Letting X represent the index of refraction, we have an equation showing how this index may be always obtained

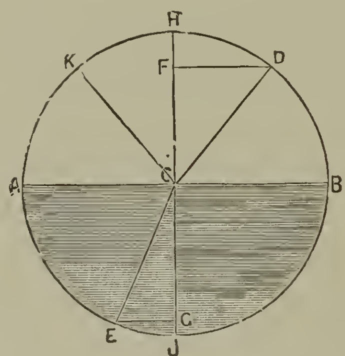


Fig. 2.—Illustrating Reflection and Refraction.

as follows: $X = \frac{DF}{EG}$. After obtaining the index of refraction of a given medium its refractive power may be readily found. Experiments show that if the square of the refractive index, less unity, is divided by the specific gravity, the result will give the refractive power of the given medium. If we let R represent the refractive power and S the specific gravity of the given medium the following equation will show how the power of refraction is obtained: $R = \frac{X^2-1}{S}$. The following tables show the index of refraction of each of the media mentioned when the ray passes from vacuum, and the refractive powers of the more important of these media:

| | X | R |
|---|---|---|
| Air, . . . . . . . | 1.000 | 0.4528 |
| Ice, . . . . . . . . | 1.130 | |
| Water, . . . . . . . | 1.336 | 0.7845 |
| Cornea, . . . . . . . | 1.336 | 0.7986 |
| Crystalline lens, . . . . . | 1 414 | |
| Crown glass, . . . . . . | 1.500 | |
| Rock crystal, . . . . . . | 1.562 | 0.5415 |
| Flint glass, . . . . . . | 1,575 | 0 7986 |
| Diamond, . . . . . . | 2.480 | 1.4566 |

In the refraction of a ray of light a portion of it is also reflected. Thus in figure 2, while the incident ray DC is refracted along the line CE, a portion of it is at the same time reflected along the line CK; and as already noticed the angle of reflection formed by it, KCH, is equal to the angle of incidence, DCH.

*Total Reflection.*—What is known as internal or total reflection is a very interesting and instructive phenomenon. As one looks down perpendicularly into clear water, he can readily see the bottom unless very deep. The same is true if he looks down at any angle greater than about 48°. Objects on the bottom, as already explained, are made visible by reflecting from their surfaces the light resting upon them. But when a ray of light is reflected from water to air at any angle less than 48° it does not pass into the air. It is totally reflected. Consequently, when looking into the water at an angle of 48° or less, all the light radiated toward you from the object toward which you are looking, instead of reaching your eyes, suffers total reflection. The same principle applies when light passes upward at certain angles from one stratum of air to another of different density. If the ray inclines at the proper angle it will, on reaching the second stratum of air, be reflected back toward the earth, at the same angle at which it ascended, forming equal angles of incidence and reflection. Thus the observer, standing in the

path of light internally or totally reflected, is able to see objects beyond the horizon of his view. Their images are first thrown upward by incident rays and then back to the earth by reflected rays. This explains the mirage of the sea and of the desert.

The angle of total reflection differs for different substances. When the ray passes from diamond to air it is 23°-|-, from flint glass to air 38°-|-, from water to air 48°-|-.

## LESSON III.

### Refracting Media.

*Ocular Refraction.*—The refracting media of the eye were briefly described in Lesson I. They constitute the dioptric apparatus of the eye, through which is fulfilled its function as a refracting instrument. Cornea, aqueous humor, crystalline lens and vitreous humor all act in unison like a single lens. In an examination of the different kinds of lenses we shall find illustrations of the eye's refractive character. Most of these lenses are shown in Fig. 3.

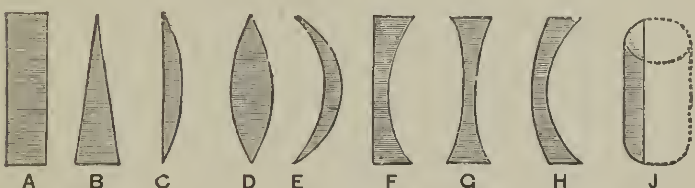


Fig. 3.

*Varieties of Lenses.*—Any transparent substance constitutes a refracting medium. But the present discussion is chiefly interested in the refractive characteristics of lenses, simply, and their relation to, and illustration of the refraction of the eye.

Lenses are divided into four general classes, plano, prismatic, spherical and cylindrical. The names distinguishing them describe their surfaces. In a plano or plane lens, A, the two surfaces are parallel. The surfaces of a prismatic lens, B, incline toward each other from base to apex. A spherical lens is ground on a spherical disc, the section of a sphere. There are two classes of them, spherical convex and spherical concave. The

former are thicker at the center than at the edge, sloping regularly in every direction from the center. The latter are thinner at the center than at the edge, sloping regularly from every direction toward the center. C, D, E, F, G and H are the spherical lenses. A cylindrical lens is ground on the inside of a section of a cylinder, if convex, and on the outside if concave, and in form corresponds to a section of a cylinder. Plane cylindrical lenses are divided into the two general classes, cylindrical convex and cylindrical concave. Along the axis of a plane cylindrical lens it does not vary in thickness. From this axis a cylindrical convex lens grows gradually thinner outward to the two opposite sides or edges. The dotted lines serve to show the cylinder of which the cylindrical convex lens J is a part. A cylindrical concave lens grows gradually thicker outward to the two opposite edges. Its refracting surface is curved inward, being concave instead of convex. Suppose the plano side of the cylindrical convex lens to remain the same and its convex side to be concaved instead of convexed, then you have a plane cylindrical concave lens in place of the plane cylindrical convex shown in the diagram. At all points along the same meridian, parallel with its axis, a plane cylindrical lens is of the same thickness. On meridians at other angles to its axis the lens is of varying thickness, with this qualification, that points equi-distant from the axis on opposite sides are of equal thickness.

Simple cylindrical or spherical lenses may be combined with any of the other classes mentioned, thus constituting as many varieties. A sphero-cylindrical lens is ground spherical on one side and cylindrical on the other. Decenter it and it becomes a sphero-prism-cylindrical lens. A sphero-prismatic lens is spherical on one side and prismatic on the other. A prism-cylindrical lens is prismatic on one side and cylindrical on the other.

A cross-cylindrical lens is cylindrical on both sides with axes at different angles, usually right angles.

The two classes of spherical lenses, convex and concave, are respectively subdivided into three other classes, viz: plano convex, double convex, periscopic convex, and plano concave, double concave, periscopic concave.

A plano convex lens, C, is plano on one side and convex on the other. A double convex lens, D, is convex on both sides. A periscopic convex lens, E, is convex on one side and slightly concave on the other; but its convexity having a shorter radius of curvature, exceeds its concavity, so that it falls within the description of convex lenses, being thicker at the center than at the edge, and so its nature is that of a convex lens. It is sometimes called a concavo-convex lens.

"Periscopic" means to see around. Lenses are so ground because they thus enlarge somewhat the scope of vision. A plano concave lens, F, is plano on one side and concave on the other. A double concave lens, G, is concave on both sides. A periscopic concave lens, H, is concave on one side and convex on the other, but the concave side has a shorter radius of curvature than the covex side, and so it falls within the description of concave lenses, being thinner at the center than at the edge. The distance from the center to the circumference of a sphere is its radius, the half of its diameter. By the radius of a spherical disc or lens we mean the radius of the sphere that would be produced from it. That is, consider a spherical disc or lens as the segment of a sphere; then consider what its degree of sphericity is and you will find how large a sphere it would make if produced; half the diameter of this sphere would constitute its radius; hence we mean, in referring to the radius of curvature in a lens, the half-diameter of the sphere of which the given degree of sphericity in the lens makes it a part; which length of radius is also the

chief factor in determining the refractive power of the lens. This prepares us to observe the important principle that the shorter the radius the stronger the refractive power of the lens, whether it be convex or concave, its center as compared with its edge being proportionately thicker in convex and thinner in concave lenses.

*Properties of Lenses.*—A refracting medium with parallel sides, as a plano lens, Fig. 4, bends an oblique ray entering it, and then bends it back again into its original direction as it emerges. The actual direction of an object seen through such a medium is, therefore, the same practically as its apparent direction. The

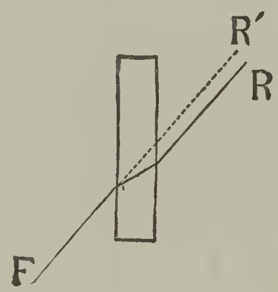


Fig. 4.

apparent place of the object, however, is slightly different from the actual place. In Fig. 4, the light reflected from the object (or radiant) at R, its actual place, enters the eye on the line R′F, as though located at R′, and so makes the object appear at R′. The object appears, according to a law of refraction, on a line with the direction from which the ray enters the eye. As the apparent is separated from the actual place but about the width of the refracting medium, no disturbing effect is experienced in the use of window or other plane glass. Plano lenses are used largely in colored optical goods. In above figure and others following, R is the radiant point and F the location of the eye or *focus*.

*Prisms* illustrate the fundamental principle that a ray, in passing through a lens of unequal thickness, is always refracted toward its thickest part. Rays proceeding from an object at R, its actual place, Fig. 5, are so refracted that the object appears at R′, a point in line with the direction from which the rays enter the eye.

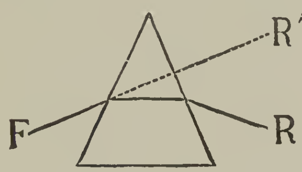


FIG. 5.

Keeping in mind the above principle, that a ray is always refracted toward the thickest part of a lens, we readily see what the refractive effect of a *spherical lens* must be. A ray passing through the center of such a lens, on the line of its optical axis, will not deviate from a straight line. Passing through the lens at any point one side of this center, however, it will be refracted either toward or from the center; if the lens is spherical convex, toward the center, that being the thickest part, if spherical concave, from the center, the thickest part being at the edge.

This enables us to see how the rays in a pencil or cone of rays impinging upon a spherical lens are refracted. Let us suppose the radiant point to stand in the line of the optic axis and so opposite the center of a spherical convex lens, the circle of diverging rays proceeding from the radiant being made thereby to impinge upon the lens in such manner that each ray in the circle is equi-distant from the center of the lens. This brings the cone of the lens directly under the cone of rays. The rays diverge as they proceed from the radiant point. Reaching the convex lens they are refracted toward its center, that

being its thickest part, and so toward each other. Consequently as they proceed from the lens they are converged together to what is known as the focal point. In their divergence the rays constitute a cone having the radiant point for its apex with its base upon the lens. In their refracted convergence they constitute another cone having its base upon the other side of the lens, bringing their bases together and their apices at points correspondingly opposite each other. These are the conditions when the lens is convex: there are two cones with bases together. Where the lens is spherical concave there are two cones also, but differently situated. The cone reaching from the radiant point to the lens is the same as it is in the spherical convex. But the second cone is not the same. It is formed by the rays diverged as they pass through the lens. Its base is upon any object which intercepts them. Its apex, which is its virtual focus, is found by producing the diverged rays backward to the point of their intersection. Instead of apices being opposite each other as in the case of a convex lens they lie in the same direction. one cone sitting over and upon the other.

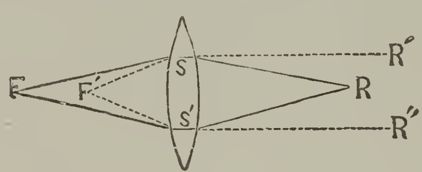


Fig. 6.

*Conjugate Foci.*—Refractive effects upon a single ray of light are comparatively simple. But in nature we deal with innumerable pencils, each composed of a multitude of rays. This makes the subject more complex. Let us simplify it as far as possible by beginning with a single divergent pencil, and only two rays of said pencil, viz: R S and R S′, Fig. 6. From R, a radiant point, the pencil

diverges in the form of a cone. The spherical convex lens S S′ so refracts its rays that they form a convergent pencil with focus at F. The two points, R and F, are interchangeable. That is, if the radiant were placed at F, the focus would be at R. This is true whether the distance from the lens to each point is the same or different. The relation of the two points is such that the nearer the radiant is placed to the lens the farther from it the focus will be removed, and *vice versa*. These two points at which a radiant and its focus or image are respectively located are called *conjugate foci*.

*Principal Focus*.—As stated the focus formed from parallel rays has special significance in optics. It constitutes what is known as the *principal focus* of a lens. Whenever we speak of the focus or focal power or distance of a lens its principal focus is meant, unless otherwise stated. The focal or refractive power of a lens is measured by the distance from it that parallel rays passing through it form a focus. This is called its focal distance. The stronger the lens the nearer to it will this focus be formed, and *vice versa*. In Fig. 6, F′ is the principal focus being formed by the parallel rays R′S and R″ S′.

Notwithstanding nature projects only divergent pencils, still, rays coming from a great distance, as the sun, approach us on substantially parallel lines. Direct solar rays, therefore, are best adapted to measuring the power of lenses. In measuring the power of the eye rays coming fifteen or twenty feet are nearly enough parallel for practical purposes.

Remembering that a radiant and its focus are interchangeable, constituting conjugate foci, let us suppose the radiant placed at the point of the principal focus, F′. The rays diverging from it will be refracted upon parallel lines, exactly retracing their former paths S R′ and S′ R″. If the radiant is removed from the lens the

refracted rays will proportiontely increase their convergence, and if it approaches the lens they will proportionately decrease their convergence.

Applying some of the foregoing principles, suppose the lens S S′, Fig. 6, represent the refracting power of the eye. When looking at objects beyond 15 or 20 feet rays will enter it on parallel lines just as R′ S and R″ S′ approach the lens, Fig. 6, and will be converged to a focus on the retina as the above rays are refracted to F′. On the other hand, when reading or looking at objects near by, rays enter the eye upon lines more or less divergent like R S and R S′, and are in like manner converged upon the retina, as at F. By a most wonderful provision, called accommodation, (to be explained under the head of normal vision), the eye is able to make the points F, F′, and all intermediate foci fall at the same point upon the retina, thereby making near and distant vision both possible with the same refracting media. This is possible simply because the eye's accommodation enables it when necessary, to bring the focal point from F to F′, as will be explained in the proper place.

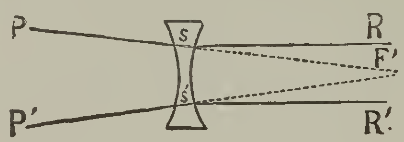


FIG. 7.

In illustrating, as above, how parallel rays give the principal focus of a lens we naturally use a spherical convex lens, which converges the rays. A spherical concave lens instead of converging diverges the rays. To find its *principal focus* we trace the refracted rays S P and S′ P′, Fig. 7, back to the focal point from which they seem to diverge, F′. Being the principal focus in a virtual sense, it is common to call this point the *virtual focus* of the

given concave lens as stated in a previous paragraph explaining how the second cone in a concave lens is produced and its apex or virtual focus located. Its distance from the lens represents the focal power of the latter. If convex and concave lenses of equal power are placed together they neutralize each other, producing the effect of plane glass. As convex lenses enlarge objects the term magnifying glasses is sometimes applied to them, and the term diminishing glasses is applied to concave lenses, because they minify objects.

A radiant projects rays in every possible direction we have seen. As a result the space of the cone bounded by R S and R S′, Fig. 6, must be filled with rays impinging upon different points in the surface of the lens. These rays strike the lens not only at different points but at different angles. Some of them in consequence are bent out of their original direction more than others, no uniformity of deviation between the different rays being observed. How then, it may be asked, do these rays all reach the same point so as to form a focus or image of the radiant? The answer is that the degree of refraction produced by a lens corresponds to the degree of obliquity at which a ray strikes it, and the relative thickness of the lens at its center as compared with its edge. By the proper grinding of lenses these conditions may be secured. Hence we are thus enabled to determine their refractive power.

*Numbering Lenses.*—Plano lenses are described by their color, as white, smoked, blue, violet, orange, etc. Prisms, we have seen, are of a wedge-like shape. They are described by the angles which their sides make with each other, as a prism of 2° or 8° or 20°, etc. As already noticed, simple spherical and cylindrical lenses are each divided into two classes, convex and concave. The different lenses in each class are distinguished and described by their respective powers of refraction. These refractive powers are represented by numbers. If No. 1,

for example, be taken for the unit of a given system, then a lens twice as strong as the unit is marked 2, and three times as strong, 3, and seven times as strong, 7, and so on. Likewise a lens one-half as strong as the unit is naturally represented by $\frac{1}{2}$, and one-fifth as strong, by $\frac{1}{5}$, and one-fortieth as strong, by $\frac{1}{40}$, etc. Thus the number properly representing a lens expresses its relative power of refraction as compared with the unit adopted.

*Two Systems.*—Until within a generation there was no uniform system of grinding and marking lenses. Each manufacturer adopted an arbitrary series of refractive powers to suit his notion, and ground and numbered his lenses accordingly. As these series had no scientific or common basis, No. 10 of one manufacturer might be No. 13 of another, or intermediate between 7 and 8 of another, and so on. The inconvenience of this want of uniformity has led successively to the development of two systems.

*Inch System.*—What may be called the inch system came into use some thirty years ago. Its unit is a lens having a focal power of one inch. That is, the principal focus of this unit lens is formed at a distance from it of one inch. The refractive power of this unit lens is represented by its equivalent fractional form $\frac{1}{1}$. A No. 2 lens, in the inch system, is situated two inches from the principal focus, and is properly represented by its refractive power $\frac{1}{2}$, as it is one-half as strong as the unit. A No. 10 lens, in the inch system, is ten inches from its principal focus, and is represented by its refractive power $\frac{1}{10}$, being one-tenth as strong as the unit, and so on.

This unit of the inch system is so strong as to be rarely used in practice. The other lenses in the system, being weaker than itself, are fractional parts of it, and so their refractive powers are properly expressed in the fractional, not integral form.

Take, for example, a No. 20 lens, as commonly designated, the focal distance being 20 inches, and whenever we wish to estimate its value the fraction $\frac{1}{20}$ must be employed instead of the integer 20, because the former and not the latter represents its refractive power. Accordingly, in all additions, subtractions, or other comparisons between lenses, in the inch system, we are compelled to resort to common fractions.

The farther fact appears that the focal distance increases as the refractive power diminishes, and *vice versa;* and this is true of each system of refraction. The refractive power and focal distance vary inversely. To illustrate, compare a 4 inch with an 8 inch lens. The refractive power of the latter, $\frac{1}{8}$, is only half that of the former, $\frac{1}{4}$, but its focal distance is twice as great.

As may be inferred from the above, a standard of numbering lenses, to be satisfactory, must be based either upon focal distance or refractive power. In the earlier efforts to adopt a uniform standard the radius of curvature of the two surfaces was made the basis of measurement. If a disc had a radius of seven inches it was supposed to grind the surface of a No. 7 lens—a lens with a seven inch focus—providing the opposite surface was plane. Grinding both surfaces by the same disc makes the lens twice as strong. For instance, the above No. 7 lens would thus become 3½.

This would have been a satisfactory standard if the curvature of a lens were the only element determining its refractive power, or if the other element determining it, its index of refraction, were uniform. Or, if this index always amounted to 1.50, the above standard would answer, for then the radius of curvature and focal distance would correspond. But the index of refraction of glass is variable. On the average it is about 1.53. To depend, therefore, on the radius of curvature, is to mark most lenses weaker than their actual powers of refraction.

*Dioptric System.*—Any standard based upon the radius of curvature is manifestly unsatisfactory. For reasons yet to be mentioned, the inch system, even when based upon focal distance, has failed to retain the approval of leading thinkers in optics. Dissatisfaction had become so general that the Paris Ophthalmological Congress of 1867 appointed a commission to devise and report an improved system. Its members were O. Becker, Donders, Giraud-Teulon, Javal, Quaglino and Soelberg Wells. The congress of ophthalmogists, which met in Heidelberg in 1875, adopted unanimously what they agreed to call the *Dioptric System.* It was also adopted by the International Medical Congress which met in Brussels the same year. The unit of this system is a meter instead of an inch. That is, the principal focus of the unit lens is formed at a distance from it of one meter, which is equivalent to 39.37 English inches. Sometimes, in consequence, it is called the metrical system. The numbers in its series are known as diopters, *dioptrics* or *dioptries,* and should be followed by the letter D to indicate their system. Only three lenses in practical use are weaker than its unit. Their respective values are one-quarter, one-half, and three-quarters of a dioptry, and are expressed, decimally, as .25 D, .50 D, .75 D. The balance of the lenses in its series are stronger than the unit, and so are multiples instead of fractional parts of it. A lens twice as strong as the unit is 2 D, three times as strong 3 D, six and one-half times as strong 6.50 D, seven and one-quarter times as strong 7.25 D, etc.

The integers of the dioptric scale contain most of the refractive powers in common use, exhibiting a series of numbers with uniform intervals of one dioptry between them. But some refractive powers are used that fall between these integral numbers. By developing a scale with a uniform interval of one quarter dioptry, no needed power is omitted. This development involves, in

addition to its integers, only fractional powers capable of simple and exact expression decimally. As a consequence, the refractive powers of this scale can be handled with the ease of whole numbers.

*Systems Compared.*—The comparative merits of these systems appear as we place their points of difference side by side. To begin, their units differ widely, the focal distance of one being only an inch, while that of the other is a meter, equal to nearly forty inches. As a result refractive powers in the inch system must be expressed in common fractions, or indeterminate, circulating decimals. In the dioptric system, on the contrary, as just noted, they can be represented by integers and exact, commensurable decimals, and calculations in the latter are as simple as in whole numbers. For example, if we seek the combined powers of the two lenses, 1.25 D and 3.75 D we add them and obtain 5 D, a result which is convex or concave, whichever the two lenses are. If one is convex and the other concave their combined result is obtained by subtraction, and is found to be 2.50 D, convex or concave, whichever the stronger lens is. Like combinations in dioptries are all equally simple. But in the inch system similar combinations are more or less complex. Suppose we seek the result of combining Nos. 13 and 32, inch system. Adding their refractive powers $\frac{1}{13}$ and $\frac{1}{32}$ gives $\frac{45}{416}=\frac{1\,11}{9\,45}=\frac{1}{9\frac{11}{45}}$, a lens whose refractive power is a weak No. 9, convex or concave, whichever the two lenses are. Suppose one lens is convex and the other concave. Subtracting we obtain as the result of the combination, $\frac{19}{416}=\frac{1}{21\frac{17}{19}}$, a lens whose refractive power is a strong No. 22, convex or concave, whichever the stronger lens is. Thus, inch combinations always involve more or less tedious fractional processes, and usually give only approximate results. Obviously the dioptric is superior to the inch system in combining or comparing refractive powers. This superiority arises

from selecting a weak instead of strong lens as the unit of the refractive system, thereby making it possible to express its refractive powers in integral rather than fractional numbers.

Again, there is a uniform interval between the numbers of the dioptric scale. In the inch scale the intervals are quite variable. It is an advantage, likewise, to have the number designating a lens represent its refractive power as in the dioptric scale, seeing we deal with refractive power in our calculations, as shown above, and not with focal distance.

In case the focal distance of a dioptric number, as well as its refractive power, is desired, we have but to remember that its refractive power and focal distance stand in an inverse ratio to each other. Either inverted is equivalent to the other. If, for example, the refractive power be expressed in the dioptric system and be 2 D, the focal distance is that number inverted or $\frac{1}{2}$, that is, one-half the unit of the D system. The unit being one meter, equivalent to 39.37 English inches, one half of it gives us 19.68 inches. Hence the focal distance of a 2 D lens is shown to be 19.68 inches. In like manner, suppose the refractive power as expressed in the inch system is $\frac{1}{7}$, then the focal distance is 7 inches, or the refractive number inverted. On the contrary, reversing the process, we invert the number representing the focal distance if desiring to get the refractive power. If the focal distance be expressed as 13 inches, the refractive power will be that number inverted, $\frac{1}{13}$, or if the same distance be expressed as $\frac{1}{3}$ of a meter, (which it is within a trifle), the refractive power will be that fraction inverted or 3 D.

Still another disadvantage of the inch system is that its unit is not a uniform measure, whereas the meter is. Lenses ground according to the inch system in France will not correspond with lenses ground in Prussia, Austria, England or the United States. And these all differ

among themselves. The difference between the latter two countries, however, is so slight that we make no practical account of it.

| | | | |
|---|---|---|---|
| 1 Paris | inch | = | 27.07 mm. |
| 1 Austrian | " | = | 26.34 mm. |
| 1 Prussian | " | = | 26-15 mm. |
| 1 English | " | = | 25.40 mm. |

Dividing the number of millemeters in a meter, 1000, by the number in an inch in each country, we find the respective number of inches equivalent to a meter in each country. This shows the meter to equal 36.94 Paris inches, 37.58 Austrian inches, 38.24 Prussian inches, 39.37 English inches, and the inconsiderable variation in American inches of 39.36. In constructing the following scale of numbers in English inches, equivalent to the scale of dioptric numbers, we have used 39.37 of course. By using the number of inches equaling a meter in the several other countries we may construct a scale of Paris, Austrian or Prussian inches, respectively.

For the convenience of round numbers, as the difference is so slight as to involve no error of practical value, 40 is often used as the number of inches equivalent to a meter in place of the 39.37. And in general it may be said that, in the inch scale, particularly among the weak numbers, a small decimal may be disregarded, or where it is larger, a unit may be added to the integer, as in the above case in making it 40 instead of 39.

The superiority of the dioptric system points to its ultimate adoption. But so long as both systems remain in use we shall often need to transpose from one to the other. In doing this it must be remembered that the refractive unit of the dioptric system, 1 D, is equivalent to the focal distance of one meter, 39.37 inches, only in its inverted form $\frac{1}{39.37}$.

If 1 D equals $\frac{1}{39.37}$, then 2 D equals twice that or $\frac{2}{39.37}=\frac{1}{19.68}$, and 3 D equals three times that or $\frac{3}{39.37}=\frac{1}{13.12}$, etc. Hence the rule to reduce dioptric to inch numbers: *Multiply the fraction which represents the refractive power of one dioptry, expressed in the inch system, viz.,* $\frac{1}{39.37}$, *by the number of the dioptries to be transposed, and reduce the resulting fraction to its lowest terms.* To do this, take the numerator as a divisor and divide both the numerator and denominator by it, as was done in finding the lowest terms above when reducing 2 D and 3 D, respectively, to inch numbers. This will give a fraction, representing the refractive power, whose numerator is 1 and whose denominator is the number or focal distance in inches, of the equivalent power, in the inch system. The reason of the rule is plain. If a certain fraction represents in the inch system the refractive power of 1 D, then that fraction multiplied by any number of Ds will give the refractive power of the given number of Ds in the inch system. Reversing the process, we discover the following rule for transposing inch numbers into equivalent dioptries: *Divide the inch number to be transposed (expressed fractionally, as the fractional form only gives the refractive power in the inch system) by the refractive power of one dioptry, expressed fractionally in the inch system, viz.: by* $\frac{1}{39.37}$, *and the result will be the equivalent number in dioptries.* The reason of the rule is plain. The refractive power of any number of inches divided by the refractive power of 1 D will show how many Ds there are in the given number of inches. To illustrate, take a 13-inch lens. Its refractive power is $\frac{1}{13}$. Divide that by $\frac{1}{39.37}$ and we have, after inverting the divisor and proceeding by multiplication according to the rules for the division of fractions: $\frac{1}{13} \times \frac{39.37}{1}=\frac{39.37}{13}=3$ D. The decimal, .37, which is left after dividing the numerator by the denominator is so small in value that in practice we disregard it.

Observing these principles, we have developed the following scales of dioptric numbers and their equivalents in focal inches. In strictness, as the dioptric numbers give refractive powers, the inch scale should be written in the fractional form, so that it will do the same. But this would involve very complex fractions. So we use the integers and decimals expresssing focal distances, since focal numbers are commonly used in the inch system. For the sake of greater simplicity and exactness, the indeterminate focal number is expressed decimally and carried out into its circulating decimal two places.

## DIOPTRIC SCALE WITH EQUIVALENT INCH NUMBERS.

| DIOPTRIES. | INCHES. | DIOPTRIES. | INCHES. | DIOPTRIES. | INCHES. | DIOPTRIES. | INCHES. |
|---|---|---|---|---|---|---|---|
| .25= | 157.48 | 5.25= | 7.49 | 10.25= | 3.84 | 15.25= | 2.58 |
| .50= | 78.74 | 5.50= | 7.15 | 10.50= | 3.74 | 15.50= | 2.54 |
| .75= | 52.49 | 5.75= | 6.84 | 10.75= | 3.66 | 15.75= | 2.49 |
| 1.00= | 39.37 | 6.00= | 6.56 | 11.00= | 3.57 | 16.00= | 2.46 |
| 1.25= | 31.49 | 6.25= | 6.29 | 11.25= | 3.49 | 16.25= | 2.42 |
| 1.50= | 26.24 | 6.50= | 6.05 | 11.50= | 3.42 | 16.50= | 2.38 |
| 1.75= | 22.49 | 6.75= | 5.83 | 11.75= | 3.35 | 16.75= | 2.35 |
| 2.00= | 19.68 | 7.00= | 5.62 | 12.00= | 3.28 | 17.00= | 2.31 |
| 2.25= | 17.49 | 7.25= | 5.43 | 12.25= | 3.21 | 17.25= | 2.28 |
| 2.50= | 15.74 | 7.50= | 5.24 | 12.50= | 3.14 | 17.50= | 2.24 |
| 2.75= | 14.31 | 7.75= | 5.08 | 12.75= | 3.08 | 17.75= | 2.21 |
| 3.00= | 13.12 | 8.00= | 4.92 | 13.00= | 3.02 | 18.00= | 2.18 |
| 3.25= | 12.11 | 8.25= | 4.77 | 13.25= | 2.97 | 18.25= | 2.15 |
| 3.50= | 11.24 | 8.50= | 4.63 | 13.50= | 2.91 | 18.50= | 2.12 |
| 3.75= | 10.49 | 8.75= | 4.49 | 13.75= | 2.86 | 18.75= | 2.09 |
| 4.00= | 9.84 | 9.00= | 4.37 | 14.00= | 2.81 | 19.00= | 2.07 |
| 4.25= | 9.26 | 9.25= | 4.25 | 14.25= | 2.76 | 19.25= | 2.04 |
| 4.50= | 8.75 | 9.50= | 4.14 | 14.50= | 2.71 | 19.50= | 2.01 |
| 4.75= | 8.28 | 9.75= | 4.03 | 14.75= | 2.66 | 19.75= | 1.99 |
| 5.00= | 7.87 | 10.00= | 3.93 | 15.00= | 2.62 | 20.00= | 1.96 |

*Materials of Lenses.*—In the manufacture of optical lenses two different materials are used. One, the product of art, is glass. The other is a product of nature, known to mineralogists as rock crystal and to opticians as pebble, or transparent stone. The generic name quartz embraces a whole family of minerals known as agate, amethyst, carnelian, chalcedony, jasper, ruby, rock crystal, etc. Rock crystal—pure quartz—is colorless and transparent. Foreign substances frequently enter into its composition and color it. When the color is violet-blue or purplish violet it is called amethyst; when red, ruby; when white and waxy in luster, chalcedony; and where the tints of the latter are flesh-like and reddish, carnelian; when smoky or brown, smoke quartz or cairngorm stone, etc. Variegated colors characterize some varieties as agate and jasper. Egyptian pebble is a brownish yellow jasper. Scotch pebbles is a term often applied to agates found in Scotland. Brazilian rock crystal being deservedly famous for its superiority is in largest demand for pebble lenses.

Before the manufacture of glass had reached its present state of perfection the preference for pebbles was well justified and quite pronounced. As formerly made the elements of glass seemed subject to some atmospheric rearrangement or modification which rendered it cloudy. The purity and transparency of the best glass now made relieves it of this disparagement. Nevertheless, there still remains sufficient superiority in pebble to make it deservedly popular. This is largely due to its hardness which renders it susceptible to a high degree of polish and prevents it from being easily scratched. It is a common annoyance in the use of glass lenses that their surfaces are very liable to become marred. Being tougher than glass and of a higher index of refraction pebble lenses can also be ground thinner and so be made lighter.

Rock crystal, in a particular direction, may reveal the property of double refraction. When the block is thick enough an object seen through it in the given direction reveals two images. If the piece of crystal is thin there is one image, but it appears bi-refringent or blurred in outline. Rock crystal blocks are sawed into slabs preparatory to being ground into lenses. These slabs should be so cut that the axis of the lens will be at right angles to the axis of double refraction. They are then called axis-cut pebbles. In order to economize material this rule is not strictly observed always, and worthless lenses is often the result. Not only are such lenses inferior to the poorest glass but positively injurious to the sight.

However, it cannot be said that all non-axis cut pebbles are worthless. Indeed there are those who argue that carefully cut non-axis pebbles may be made little if any inferior to axis cut. But no one will dispute that the cutting may be carried to such an extreme in the direction of economizing material as to result in lenses that are of negative value.

*Qualities of Lenses.*—An expert can distinguish a pebble from a glass lens by examining its edge. Pebble being a better conductor of heat and consequently colder than glass, almost any one may distinguish between the two by touching them to the tongue. A still better test is found in the pebble tester. It consists of two tourmaline plates pressed together in a coiled wire frame so made that a lens can be held between them, and also so that the plates can be rotated. When rotated so that their axes are parallel, and consequently their grain, light can be seen through them of a yellowish brown or brownish green color. The plates are cut with the grain of the crystal. More light can be seen through them in this position of parallelism than in any other. Continue to rotate from this position and the light will gradually diminish until the directions of the

grain of the two plates are at right angles to each other, when total darkness will result. In this last position place a glass lens between the plates and no change occurs. It is still dark as you look through the plates, or rather hold them close to the eye between it and the light and try to look through. Now take out the glass lens, put in its place a pebble lens and look again and one or more of the colors of the spectrum will appear. Non-axis cut pebbles are likely to show but one color; axis-cut, several. It is not unnatural to infer, as is done, that the more perfect the pebble the more full and sharp will these colors appear.

Lenses of first quality, whether pebble or glass, are clear and perfect in polish and transparency, being free from all wavy lines, bubbles, specks and other imperfections. Lenses are graded downward as I, II, III, etc. Of necessity the cheaper goods contain inferior grades. This is particularly true of "imported goods."

*Aberration, Spherical and Chromatic.*— Each cone of rays impinging upon a convex lens ought, according to the formal statement of the law of refraction, to be converged to a single focal point on the axis of the lens. Practically speaking this statement is inexact. The outer and inner rays of the cone reach focal points on the axis of the lens at some distance apart. Intermediate rays reach intermediate focal points along the axis. The rays passing through the lens farthest from its center are refracted most, and so converged to a focus on its axis nearest the lens, and those passing through nearest the center are refracted least and so converged to a point farthest from the lens, and all other rays in the cone intermediately situated are converged to points correspondingly intermediate though inversely related. This peculiarity of a spherical lens is called *spherical aberration.* It interferes with clear vision by preventing a sharp outline of the object. A lens can be so constructed

as to bring all the rays to a point and thus obviate this interference. Such a lens is called aplanatic. The peripheral rays are the cause of the interference. In optical instruments it is prevented by a diaphragm which excludes all but the more central rays. The iris constitutes the diaphragm of the eye, through the pupil of which only the more central rays are admitted, the peripheral rays being thereby excluded and spherical aberration reduced to zero, or at least to the minimum.

*Chromatic Aberration* is due to the unequal refrangibility of different colored rays of light. Red is refracted less and violet more than any other color. The other colors in the solar spectrum have degrees of refrangibility varying all the way between the extremes, as illustrated in the rainbow. We have already referred to this under the common designation of refractive dispersion. Rays that are at equal distances from the center of a lens, as we have just seen, do not suffer spherical aberration. It occurs only between rays when they are at unequal distances. It has reference simply to the different points at which differently situated rays may be focalized. Chromatic aberration, on the other hand, has reference to the different parts of the same ray. Each ray of white light may be split into the different colors of which it is composed, because the degrees to which the different colors are refracted vary, and so they may be dispersed and displayed at different points in the spectrum. The highest degree of refraction occurs in the violet, the next degree in the blue, and so on to the red, which shows the lowest degree. Prisms develope this dispersion of the colors. A ray entering a darkened room through a shutter may be passed through a prism and the spectrum colors thrown upon a screen and displayed in order. The violet end of the spectrum will be toward the base and the red toward the apex of the prism. The prismatic effect of rain-drops causes the rainbow. Chromatic aberration

is revealed in the dioptric media of the eye to a slight extent, but under ordinary circumstances it scarcely interferes with sharpness of vision, according to such authors as Helmholtz and Donders. The function of the iris and the small size of the pupil protect against chromatic as well as spherical aberration. In large instruments, as telescopes, the interference of chromatic aberration would become serious were it not counteracted. For the purpose of overcoming it an achromatic lens is used. This consists of a lens made double, one part being flint and the other crown glass. The dispersive power of crown glass is considerably less than that of flint. By observing their differing ratios of refraction and dispersion, flint and crown glass lenses may be so combined as to neutralize this aberration of color. Achromatic lenses are indispensable to satisfactory observations of the heavens. But the difficulty of making them is too great and their service in spectacles too inconsiderable to lead to their use therein.

*Grinding Lenses.*—The grinding of a lens determines its refractive character and power. This grinding is done upon metallic discs. These consist of segments or sections of spheres and cylinders. If the segment of a hollow sphere be set revolving and a slab of glass be held firmly against its outer surface, a spherical concave lens will be ground. If it be held against its inner or concave surface a spherical convex lens will be ground. In like manner a hollow cylinder may be set revolving and a cylindrical concave lens be ground on its outer and a cylindrical convex lens on its inner surface. When ground to the proper form the surfaces of the lens are polished with fine felt and rouge. The smaller the sphere or cylinder the stronger the lens, and *vice versa.* Most lenses in common use are ground on large discs, in quantities, by the cheap labor of foreign countries.

Otherwise they could not be produced at a cost so surprisingly low. All lenses, compound or simple, ground to order, have to be made here one or so at a time. This involves a considerable extra expense. If one side is ground spherical and the other cylindrical, the lens is called sphero-cylindrical; one side spherical and the other a prism makes it sphero-prismatic; one side cylindrical and the other side prismatic makes it a prism-cylindrical; both sides cylindrical makes it a cross cylindrical. An equivalent sphero-cylindrical can always be substituted for a cross. These definitions indicate the constitution of compound lenses and how to grind them.

*Centering Lenses.*—Even after deserved attention has been given to the foregoing points, the value of a lens may be seriously if not quite impaired by neglect to center it. The optical center of a lens is its cone. In a spherical convex lens this is its thickest point, and in a spherical concave, its thinnest. In cutting and finishing the edge of the lens, oval or round, it should be so cut that the extreme points of every meridian through its center shall be equi-distant from that center. This is necessary to bring the cone directly before the pupil of the eye, which is indispensable to proper vision. The centering of lenses involves additional cost and care, as is evident, but their enhanced value far exceeds the extra expense. Not only may its setting throw the cone out of center, but the lens may be so ground that the cones on the two sides will not be opposite each other.

Again, the lenses may be properly ground and centered and their value still be neutralized by neglect in fitting and making the frame. Its pupillary distance and other dimensions must be exact to avoid throwing the center of the lens off the visual axis and so out of line with the pupil. These requirements are leading a constantly increasing number of patients to appreciate the importance of having their glasses made to order. That the

optical fitting of the face and eyes should be correct is vastly more important than that the hat should fit the head, the glove the hand, or the shoe the foot.

*Abbreviations, Signs, Etc.*—To simplify the writing of prescriptions and orders, abbreviations and signs are usually employed. Absolute uniformity in their use does not obtain, but there is substantial agreement. By a captial D placed after a focal number or refractive power, dioptries are meant. In its absence the number is understood to be given in the inch system.

Names with equivalent abbreviations are indicated below:

| | | |
|---|---|---|
| Pl. | equals | Plano. |
| S. or Sph. | " | Spherical. |
| C. or Cyl. | " | Cylindrical. |
| Cx. | " | Convex. |
| Cc. | " | Concave. |
| D. Cx. | " | Double Convex. |
| P. Cx. | " | Periscopic Convex. |
| D. Cc. | " | Double Concave. |
| P. Cc. | " | Periscopic Concave. |
| Col. | " | Colored. |
| Coq. | " | Coquille. |
| Smo. | " | Smoked. |
| Bl. | " | Blue. |
| Vi. | " | Violet. |
| Or. | " | Orange. |
| O. D. or R. E. or R. | " | Right Eye. |
| O. S. or L. E. or L. | " | Left Eye. |

The terms right eye and left eye are, in Latin, respectively, *oculus dexter* and *oculus sinister;* hence the abbreviations. Where both eyes are alike O. U. is sometimes used, standing for *oculi uno*, which means the eyes together.

Since lenses, regarded with reference to their principal effect are divided into two general classes, designated respectively convex and concave, or convergent and divergent, or sometimes magnifying and diminishing, we

are able to simplify the writing of prescriptions still farther. Convex lenses are regarded as positive and so are indicated by the sign +; concave lenses, accordingly, are negative, and so indicated by the sign —. To indicate the angle at which the axis of a cylindrical lens is to be set we write the abbreviation ax. and follow it by the number of the angle required, at the upper right hand of which we place the sign for degrees, °. The word prism in connection with a given number, at the upper right hand of which is placed the character °, indicates the degree or strength of the prism to be used. The sign in compound prescriptions, used to show the combination of two lenses in one, is the following, $\supset$; where the prescription is for a cross cylindrical lens the following sign of combination is often used instead, $\ulcorner$.

A prescription or optical formula written as follows:

$$-\ 3\tfrac{1}{4}\ \text{Ds} \supset +\ 2\ \text{Dc ax. } 45^\circ$$

is to be read: Minus $3\frac{1}{4}$ dioptries, spherical, combined with plus 2 dioptries, cylindrical, axis 45 degrees. This formula, in the inch system, is properly expressed fractionally, as follows:

$$-\ \tfrac{1}{12}\ \text{s} \supset +\ \tfrac{1}{20}\ \text{c ax } 45^\circ;$$

or in the more common, though less scientific form,

$$-\ 12\text{s} \supset +\ 20\text{c ax } 45^\circ.$$

Either member of this formula written by itself calls for a simple lens, the first member for a simple spherical, and the second for a simple cylindrical. Combined as above they call for a compound lens. Compound formulas are the most difficult to understand and to fill. We subjoin a few to cultivate familiarity with their various forms.

$+ 3$ Ds $\supset + 1$ Dc ax. $95°$
$- 2$ Ds $\supset - \frac{1}{2}$ Dc ax. $125°$
-‖- $2\frac{1}{2}$ Ds $\supset$ Prism $3°$ base out.
$- 1\frac{3}{4}$ Dc ax. $65° \supset$ Prism $2°$ base in.
-‖- 1 Dc ax. $90°$ ⌈‾ $\frac{1}{2}$ Dc ax. $180°$

As mistakes and delays in filling prescriptions, and indeed, other orders also, are largely due to errors in writing them and in giving insufficient data, we commend the subject to the careful attention of opticians.

## LESSON IV.

### Reflecting Media.

*Ocular Picturing.*— In its essential function the eye is a picture-making instrument. The rays diverging from each radiant point are so combined and converged by the refracting media as to constitute a double cone whose second apex reproduces that point upon the retina in a picture of it. Pictures of all the radiant points upon the object are thus produced upon the retina in the same mutual relationships as upon the object, thereby constituting an image of it. Take off the outer coats of the eye of a dead animal and this image may be seen. The image thus thrown upon the retina is reflected from it outwardly. Through the medium of the optic nerve this image is also reflected backward to the mind or sensorium of the observer. What the mind really sees, in fact, is the image, not the object itself. This function of double reflection in the retina and its associates certainly justifies our appellation, *Reflecting Media.*

*Mechanical Picturing.*— The best illustration of the eye as a picture-making apparatus is the photographer's camera obscura. The camera lens corresponds to the refracting media; the dark camera chamber to the vitreous chamber; the sensitive plate, which receives the photograph, to the retina.

*Position of Picture.*— The image on the retina is inverted and yet the object seen by the observer appears erect. When we consider the direction taken by each cone of rays the reason for the image being inverted is plain. A cone of rays proceeding from the top of the object inclines downward and so reproduces the radiant point from which it proceeds in a picture of it at the

bottom of the image. All the radiant points above the center of the object are reproduced, in like manner, in pictured points correspondingly situated, below the center of the image. Conversely, all points below the center of the object are pictured in points correspondingly situated, above the center of the image. Those on the right, likewise, are pictured on the left, and *vice versa*. As a consequence the object appears in an inverted position in the image and with its sides reversed or interchanged.

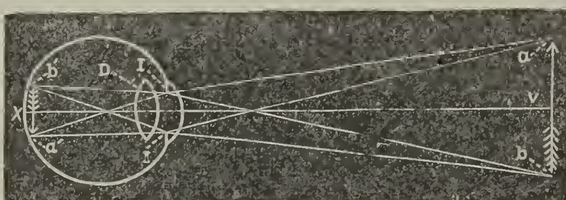


FIG. 8.

Let a b, in Fig. 8, represent an arrow, D, the dioptric system or refracting media of the eye, vx the visual axis which strikes the macula at its center, the fovea centralis, and a′ b′ the image of the arrow thrown upon the retina. Each radiant point on the arrow sends out rays in all directions. But only those rays reach the retina that pass through the pupil, the enclosure of the iris, i i. Accordingly, of the many cones of rays projected in all directions by the radiant point, a, one of them impinges upon the dioptric system of the eye and being refracted by it is converged to the point a′. Thus the double cone a c c a′ is formed, and through it a picture of the point, a, is produced at the point a′. In like manner the point, b, is reproduced in the point b′. The topmost point of the object is thereby pictured in the lowermost point of the image, and the bottom point of the object, in the uppermost point of the image. Similarly, each point in the object is reproduced in the image on the opposite

side of the latter's center from what it occupies in the object, points above being pictured below, and *vice versa*, and points at the right being pictured at the left, and *vice versa*. The central point of the object is pictured at the center of the image. As a necessary result an exact but inverted image of the object is produced.

Why the inverted image does not make the object also seem inverted has been regarded the puzzling question. The simplest answer would seem satisfactory enough and sufficiently philosophical in statement. The eye does not locate a point with reference to the relative position its picture occupies on the retina. If so the object might seem within the eye instead of external to it. On the contrary the location of a point is determined by the direction from which the rays proceeding from it enter the eye. It is as though each cone of rays constituted a finger with which the eye touched and located in its true place every radiant point in the object observed. By this thousand fingered touch the retina feels every radiant point just where it actually is and grasps the object as a whole with all its parts in their true relations. It being this touch or sense of correct position that is reflected to the mind the object is seen, as it should be, erect.

*Acuteness of Vision.*—Visual acuteness depends upon the condition of the retina, and should be carefully distinguished from the eye's refraction which is dependent upon the refracting media. Inasmuch as both affect the character of vision the two are apt to be confounded. But the refraction may be normal and some serious defect of sight still exist in consequence of imperfect visual acuteness. On the other hand retinal acuteness may be perfect and the vision still be impaired because of abnormal refraction. If the refraction is abnormal its correction is the first step; then the acuteness of vision can be determined, not before.

The sensitiveness of the skin has been used, not inaptly, as an illustration of visual acuteness or retinal sensibility. Let the points of a compass be pressed upon the skin some distance apart and two distinct sensations will be felt. As the points are brought closer together the separate sensations become less and less distinguishable until both are blended in one. The smallest distance at which the two sensations can be distinguished gives the measure of cuticular acuteness.

In the same way the eye discerns two distinct points of light, as for example two stars, when they are separated far enough apart. As they are brought closer together the two finally blend in one. The smallest distance at which the two points can be distinguished determines the acuteness of vision. That is, the visual angle formed by two rays converging upon the eye from these respective points is the measure of visual acuteness. As an angle of 1′ is the smallest at which two points are distinguishable by the average good eye that angle measures the acuteness of normal human vision. If, for illustration, two stars or any two points of light, are separated by an angular distance less than 1′ they will blend together, as contiguous stars do in the milky way. As acuteness falls below the normal standard the visual angle must be enlarged proportionately or the object will not be visible. Applying this principle we see that opposite parts or edges of an object must be separated by an angular interval of at least 1′ in order to make the object discernable. Acuteness of vision, therefore, may be defined as the visual capacity to distinguish form. When the form of the object fails to fill an angular space of 1′ it produces an image too small for retinal or mental recognition. Some have contended that while 1′ is substantially correct for terrestrial objects, an angular space at least five times as great is necessary for celestial objects.

The size of the visual angle depends upon two factors, the magnitude of the object and its distance. In Fig. 9 the object A fills the same angular space as B, and each the same as C. Each, in consequence, produces upon the retina an image of the same size; and were it not for our experience in allowing for the distance in judging of the size of an object each letter would be thought to be of the same magnitude. Thus, in proportion as the object is removed from the eye its magnitude must be increased if its image and consequent visibility are to remain the same. If, when seen under an angle of only 1′ at A, an object appears but a radiant point, then under the same angle, objects at B and C will also be radiant points simply, their angular and retinal size being no greater

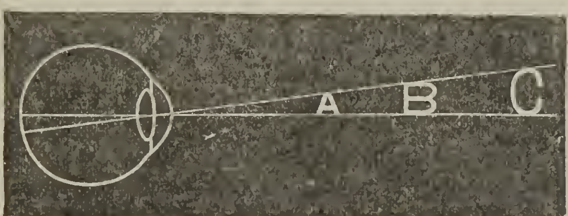


FIG. 9.

than A, all being equal. Under every larger angle objects at A, B, and C will increase in size in the same ratio as these letters do, and but for experience be regarded equal in size because their images and consequent visibility are equal, so far as determined by acuteness of vision.

This law of visual acuteness is determined by the constitution of the retina. Of the numerous layers of which the retina is composed the most important is the external one, consisting of rods and cones. These constitute the perceptive elements of the eye. There are some two hundred and fifty thousand of them acting like so many diminutive eyes directed upon the different

radiant points covering the object observed. An object seen under an angle of 1′ produces an image on the retina embracing a space of .00438 mm. The space between the cones being about this distance, their diameter being half as great, it is supposed that one condition of visual perception is that the image should fall upon two of these cones, or at least cover one of them entirely. Thus the size of the smallest perceptive retinal space determines the size of the smallest angle under which average vision is possible.

*Field of Vision.*—The dimensions above given are true, however, of the cones in the *macula lutea* only. Elsewhere on the retina they are farther apart, involving larger spaces. But this is not of great consequence as our chief visual dependence is upon *central vision*, so called, in which the sight occurs along the line of, and adjacent to, the visual axis, whose interior pole is situated at the center of the macula whereon the image must fall if the object is to be seen with directness and distinctness. The sharpest vision occurs in the *fovea centralis*, a depression at the center of the macula. Contradistinguished from central vision is *peripheral* vision, in which the image falls upon some portion of the retina surrounding the macula. Through it we get such glimpses of things lying around the object directly looked at as are necessary to warn us simply of their presence or location. While the acuteness of vision is greatest at the macula lutea, and diminishes rapidly towards the periphery, it does not do so in equal degrees. The diminution is most rapid upward and downward. The greatest *peripheral* acuteness of vision is on the temporal side of the retina. The rods and cones increase in number from the periphery toward the fovea centralis, where they are most numerous, thereby acounting for the increasing sharpness of vision.

The entire space, which at any given distance is brought under the view of both central and peripheral vision, combined, constitutes the *visual field.* The area of this field of vision enlarges, just as the visual interval does, in proportion as its distance from the eye increases. Within this space all objects, except those whose images fall on the *blind spot*, can be seen at a single glance, those images falling on the macula being sharply defined, and those surrounding it more or less vaguely outlined. But we always mean central vision, it should be remembered, when speaking of visual acuteness.

The space covered by central vision is smaller, as Carter explains, than most people would suppose without special observation. Its diameter, according to Schell, is less than one-quarter of an inch at the distance of one yard. Within this angular space the object looked at may be minutely observed in all its parts without moving the eye: the gaze may remain fixed and steady; but as soon as additional space on either side is closely inspected the axis of the eye is shifted by its muscles. In reading and in the ordinary examination of any object covering a considerable space, as a picture, the eyes are in constant motion.

*Blind Spot.*— In this connection some mention should be made of the blind spot, as it is called. Its location is determined by the entrance to the eye of the optic nerve. The opening thus made, embracing some six degrees horizontally by eight vertically, covers a space upon which, therefore, no image can be formed. Hence no perception of an object is possible when it is brought into visual line with this spot. A common experiment suggested to show this is to close the left eye and hold before the right, at a distance of eight or ten inches, a figure like number 10. While the gaze is directed steadily at the cross, move the figure slowly backward

and forward before the eye and a point will be reached where the white circle will come into line with the blind spot and so become invisible.

FIG. 10.

A still better experiment, perhaps, is to place the two thumbs side by side in an erect position, about ten inches before the face, the left eye being closed and the thumb nails visible to the right eye. Now hold the left thumb still and keep the gaze fixed upon it; at the same time move the right hand from four to five inches to the right and its thumb nail will disappear from view.

It is a very singular fact that the existence of the blind spot was not known till the latter part of the 17th century, a fact affording a most striking and truthful illustration of the prevalent ignorance of the detailed structure of the eye previous to a comparatively modern date. The discovery of the blind spot by Marriotte is said to have produced a great sensation among the learned men of Europe. At the invitation of the King, Charles the Second, the discoverer gave to the royal court a series of amusing experiments showing the presence and insensibility of this spot.

*Measuring Acuteness of Vision.*—To measure visual acuteness we must have a standard of comparison. The visual acuteness of the average normal eye naturally becomes that standard. We mean, therefore, by the acuteness of a given eye, its visual power in comparison with the average normal eye. If it falls 20 per cent. below this, its acuteness of vision is but $\frac{4}{5}$ that of an

average eye, and if it falls 50 per cent. below, it is $\frac{1}{2}$, and so on. Some eyes, on the contrary, exceed this average, showing a maximum acuteness beyond what would constitute a proper standard. The sight of children, and of savages, and of those with special training in distant vision, often exceeds this standard. A sailor or Indian, for example, may be able to descry a distant ship when it is quite beyond the discernment of average eyes. Their visual acuteness may so exceed the average as to equal $\frac{5}{4}$, or $\frac{4}{3}$, and so on.

Visual acuteness, then, signifies the power of the eye to distinguish form; the smallest object discernible at the given distance by the average eye furnishes the test adopted as a standard; and this object, as already shown, must cover an angular space of at least $1'$, in order to throw upon the retina an image large enough to be perceived,—an image having a diameter of .00438 mm. The rays employed to test acuteness must be parallel. For this reason the test object is ordinarily placed about 20 feet distant from the patient, that the rays may enter the eye on practically parallel lines.

These principles and conditions have been embodied in Snellen's Test-Types, which have become widely recognized standards. Others have followed him in producing test letters on the same principles. In his method opposite edges of the lines in each letter are situated far enough apart to fill an angular space of $1'$, and the extremes of the letter are five times as far apart, being large enough to extend across an angle of $5'$. That is, each line is made $1'$ wide, that width being necessary to render it visible to the average eye, and each letter is made $5'$ wide, experience showing that to be the proper width for comfortable continuous vision. Thus each letter is $5'$ in height, or vertical width, and $5'$ in width horizontally, and so it embraces 25 spaces, each of which is $1'$ square. In making a distance test of the eye, a

chart containing various lines of test letters of different sizes is placed in a good light before the patient at a distance of 20 feet, if possible, to exclude the accommodation. The figures placed over each line indicate the distance at which it may be read by average normal vision. For example, the line marked 20 feet can be read at that distance by the normal eye of average acuteness; a line marked 50 feet may be read at a distance of 50 feet; lines marked 15 and 10 feet can be read at those respective distances, and so on. As indicated above any short distance like 10 feet involves more or less accommodation, and to that extent is unsatisfactory. The above distances are sometimes expressed in meters instead of feet, and sometimes in yards. If an eye reads 20 foot type at 20 feet its acuteness is $\frac{20}{20}$ or 1, the unit or standard of average normal vision. The same eye will be able to read 30 foot type at 30 feet, or 50 foot type at fifty feet, or any other type at the distance to which its size adapts it. If nothing smaller than fifty foot type can be read at 20 feet the visual acuteness equals $\frac{20}{50}$ or $\frac{2}{5}$ average vision. If the same type can be read at 30 feet the acuteness equals $\frac{3}{5}$. If nothing smaller than 30 foot type can be read at 20 feet the acuteness equals $\frac{2}{3}$. If, on the contrary, 15 foot type is readable at 20 feet the acuteness exceeds the average, being $\frac{4}{3}$; likewise, 10 foot type read at 15 feet would show an acuteness of $\frac{3}{2}$, and so on.

These illustrations suggest the proper form of an equation expressing acuteness of vision. Let *va.* stand for visual acuteness, *ad.* for actual distance from chart to patient, and *nd.* normal distance, or distance at which the given type would be read if the eye were normal, as indicated by distance number of type expressed in feet or meters. This gives the equation $va. = \frac{ad}{nd}$, i. e. visual acuteness equals actual distance divided by normal distance. Thus the rule for obtaining visual acuteness gives a

fraction in which the numerator shows the actual distance from chart at which the given patient would need to stand, and the denominator shows the type distance, the distance at which a person with normal vision would stand.

It would be possible, though less convenient, to depend upon a single size of type and test the acuteness of different eyes by holding it at various distances. Each respective distance compared with the distance required by normal vision would indicate the given visual acuteness.

*Principles Applied.*—Applying the foregoing principles we place a test chart in a good light, 20 feet in front of a person, and if his vision is normal as to both acuteness and refraction, we shall find him able to read 20 foot type with the naked eye, and so shall mark his visual acuteness $\frac{20}{20}$. That means that he can read 20 foot type at 20 feet, and so has normal vision. He will also be able to read any line on test chart at the normal distance for that line, and so might properly be marked $\frac{50}{50}$, or $\frac{30}{30}$, or $\frac{15}{15}$, etc. In each case we obtain a fraction whose numerator and denominator are the same, and so equal 1, showing average normal vision. This shows that glasses are not needed for distance.

Placing the chart before a child or other person whose acuteness is in excess of the standard, we find him able, provided his refraction is normal, to read any line at a distance greater than its normal or type distance, and we mark his vision accordingly, obtaining a fraction with numerator larger than denominator, and so exceeding 1.

Placing the chart before one whose eye falls below the standard, we obtain a fraction with numerator smaller than its denominator, and so less than 1. This reveals probable abnormal refraction and the consequent need of glasses, with a possible defect in visual acuteness to be

determined after refractive error is corrected, as will appear more fully in the following paragraph.

*Acuteness and Refraction Distinguished.*—The distinction we have made between visual acuteness and refraction will now become clear. Suppose an eye normal in both acuteness and refraction, then it can read 20 foot type at 20 feet, and so its acuteness is described as $\frac{20}{20}$. Suppose another eye unable to read 20 type at 20 feet with the naked eye, then it is defective in refraction or acuteness, or both. But suppose a lens of + 2 D enables it to read 20 type at 20 feet. That shows its acuteness to be $\frac{20}{20}$ or normal, the same as the first eye, but its refraction abnormal, requiring + 2 D to correct its hypermetropia. To describe its condition we write the following equations: $Va. = \frac{20}{20}$ or 1, and $H = 2\ D$, the letter $H$ standing for hypermetropia or far-sight. Now take a third case and suppose the eye, on the contrary, unable with $+ 2\ D$ to read 20 type at 20 feet, and yet able with that lens to read the chart better than with any other; farthermore, suppose that even with this lens the eye is able to read only 30 foot type at 20 feet. This shows a defect in both acuteness and refraction and the vision is described as follows:

$$Va. = \tfrac{20}{30} \text{ or } \tfrac{2}{3}, \text{ and } H. = 2\ D.$$

Once more, suppose the eye requires — 3 $D$ and at 20 feet can only read 30 type. Then its $va. = \frac{2}{3}$ and its myopia, $M. = 3\ D$. Thus we determine acuteness and refraction at the same time and note the distinction between them. But all error in the refraction, if any, must first be corrected, so far as possible, before the visual acuteness can be determined; for visual acuteness signifies the perceptive capability of the retina, simply; and as that can be discerned only through the eye's

refraction it is evident that the latter should first be rendered as nearly normal as possible.

*Acuteness Tested at Near Point.*—To measure visual acuteness the accommodation, we have said, must be excluded, and this can be accomplished, as already seen, by using a distance test, from which rays will enter the eye on practically parallel lines. Though the same result can be reached by paralyzing the accommodating power with atropine or some other mydriatic, this is often undesirable, and always less convenient. But parallel rays can be employed even with test type at a near point, by using a convex lens just strong enough to counteract the divergence of the rays coming from the reading test. For example, with the test type about nine inches from the eye, a lens of $+ 4.50\ D$, if set where glasses usually are, about a half inch from the cornea, will cause the rays to enter the eye on parallel lines. The type will thus be read by the normal eye without any effort of the accommodation, thereby enabling us to determine the visual acuteness and also refraction with the reading as well as the distance test. This is true provided there is no abnormal tonic action of the accommodation. We have seen that with the distance test an eye having $2\ D\ H$ needs a lens of $+ 2\ D$, while a normal eye needs no lens whatever. Accordingly, in the reading test, an eye with $2\ D\ H$ will require a lens $+ 2\ D$ stronger than that required by a normal eye. Hence, if the normal eye requires a lens of $+ 4.50\ D$ at 9 inches, the eye having $2\ D.\ H.$ will require a lens of $+ 6.50\ D$ to read the same type at same distance.

When making the test the order of procedure is as follows: Having placed the reading type at about 9 inches we proceed with one convex lens after another till the strongest with which it can be clearly read is reached. If this is $6.50\ D$ it reveals, as shown by subtracting 4.50

*D* from it, that the *H* amounts to 2 *D*. If the test requires a lens of + 7.50 *D* the degree of *H* is found by subtraction to be 3 *D*. On the contrary if the eye requires — 2 *D* to read above type at 9 inches it is myopic, and we find by subtracting that its $M = 2.50$ D. By applying the formula we may thus employ near as well as distance tests to determine the visual acuteness and also the refraction of the eye.

*Practical Remarks.*—While the optician remembers that his special province is to determine errors of refraction, together with visual acuteness, in order to correct the former, and fit the eye, he should not forget that other defects of vision are liable to prevent his attaining satisfactory results. Overlooking this, he is sure to become perplexed at times in fruitless attempts to attain the impossible, and, chagrined by his disappointment, be tempted to condemn his instruments and apparatus, if not his own skill and knowledge. Proper inspection of the retina and other ocular organs will often show that the cause of impaired vision is located, in part or in whole, elsewhere than in the refracting media, and in such cases it is too much, of course, to expect all loss of visual power to be restored by the use of lenses. Where the proper use of spherical, cylindrical or prismatic lenses, or some of them in combination, fails to remove all ocular trouble we should suspect some defect in the fundus of the eye or in the transparency of its refracting media. An exceptionally nervous retina, simply, is apt to retard the progress of one's examination. Its sensitiveness may prove so disturbing as to necessitate several tests on different days, to attain the utmost accuracy. Indeed, the safest working rule is to practice the repetition of one's tests whenever possible.

Difficulty in reaching a satisfactory test promptly may also result from what will be explained hereafter as a

spasm of the accommodation. A sudden transition from light of one degree of intensity to another will disturb the vision and in consequence the tests made. "In passing from an illumination of a less to one of a greater intensity or inversely," to use the language of Landolt, "it takes about twenty-five minutes for the retina to become accustomed to the altered illumination, and to put itself in harmony with it. The acuteness of vision varies with the general illumination up to a certain degree of intensity, as that of a clear, sunny day; the two then vary in a direct proportion, but when the illumination passes a certain limit of intensity the acuteness of vision diminishes instead of increases." These illustrations indicate the need of taking into account every disturbing factor, when making a test, including recent severe illness or feeble health, with the numberless other circumstances affecting life or strength.

## LESSON V.

### Emmetropia or Normal Sight.

*Optical Construction of the Eye.*—The character of the eye as an optical instrument is determined, in the main, by its construction,—the relation of its parts. Where its construction conforms to a fundamental law of optics, now to be noticed, vision is said to be normal. To illustrate the principle involved, take a magic lantern or stereopticon. In using it its screen must be set at a proper distance in order that the picture thrown upon it may be distinct; so, also, must the lens be of the proper refractive power. In a word, the *power of the lens* and the *distance of the screen* bear dependent relations to each other, making a certain correspondence between them necessary to produce a well defined picture.

Similar relations of dependence and correspondence exist between the refracting media of the eye and its retina. A clear picture can be formed upon the latter only when it is situated at a distance that corresponds to the power of the refracting media, or (which is the same thing in effect), when the media have a refractive power corresponding to the distance of the retina. Conformity to this principle of correspondence in the construction of the eye involves conformity to the laws of optics, and so secures normal vision, because the rays are then converged by the refracting media just enough to unite at the exact distance at which the retina is located, and so form clear images upon it. When the above principle is violated the rays are converged either too much or too little to unite precisely upon the retina, and the vision is abnormal. Or, to state the average case of abnormal vision with more scientific accuracy, the *distance from the refracting media*

*to the retina* measures either too much or too little to permit the rays to form their foci exactly upon it.

The term *emmetropia* is applied to a normal eye because the distance between its retina and refracting media is "in measure," as indicated by the meaning of the word. For a like reason the term *ametropia* is applied to an abnormal eye, because it is "out of measure."

Thus it is seen that the value of the eye depends, for the most part, upon its refractive character, and that this is determined chiefly by its length, or axial diameter on the visual line. Hence the rule is that an abnormal eye is either too long or too short, while a normal eye is of the proper length. Accordingly most defects of vision really fall under the head of axial anomalies, rather than "anomalies of refraction," although they are usually discussed under the latter head. There are some defects of vision, however, that are directly due to refractive errors. And as axial and refractive errors produce similar results, it has been common, notwithstanding its inexactness, to consider them all under anomalies of refraction. Indeed, this expression, "anomalies of refraction," is a part of the title of the great work of Donders, whom another distinguished author aptly styles "our master."

It should be noted that we limit our use of the words normal and abnormal to the axial and refractive character of the eye, making them synonymous respectively with the terms emmetropia and ametropia. Any morbid or diseased condition of the eye is in some sense abnormal, to be sure, but, in the optical study of the eye, it is not unnatural to restrict the term normal to emmetropic, and the term abnormal, to ametropic vision.

*Nodal Point.*—Notice now the exact point in the refracting media from which we reckon in measuring the distance between the media and the retina. These media constitute the *refractive system* of the eye and

cover a considerable space. The point we are seeking is not located at their margin, nor of necessity at their mathematical center, but it is at their refractive center. Observe in what follows how we determine the location of this center.

The *optic axis* is a line passing through the center of the refractive system, successively piercing the middle of the cornea, aqueous humor, crystalline lens and vitreous humor. The visual axis is the center line of vision, having its inner or ocular pole at the center of the macula lutea, and its outer pole at the center of the field of vision. Naturally we might suppose that the visual axis and optic axis would coincide. But they do not, or rarely do. Now the point which we seek is where these two axes cross each other. This is the point from which we reckon the distance to the retina, as it is the center of the refractive system. It is known as the *nodal point*, and is situated near the posterior edge of the crystalline lens. The angle formed by these two axes is known as the angle *a*.

The macula, and consequenty the ocular pole of the visual axis, is usually located on the temporal or outside of the ocular pole of the optic axis. But the two axes sometimes approach till they coincide, and even till their relations become reversed by the ocular pole of the visual axis falling inside the ocular pole of the optic axis. The latter condition is most liable to occur in high degrees of myopia. On the contrary the ocular pole of the visual axis is outside the optic axis, in both emmetropia and hypermetropia, but is farther out in the latter than in the former.

*Eye at Rest.*—Brief reference was made in the first lesson to the fact that the crystalline lens is capable of varying its thickness and thereby its refractive power. Increasing its refraction increases proportionately the eye's capacity to see objects near by. While adjusted for near vision by this increase of power the ciliary muscle is

subjected to more or less exertion according to the nearness of the object examined. In the absence of this exertion the eye is adjusted for distant vision and is then said to be at rest.

Now it must be borne in mind that all that has been said thus far in the present lesson about either the emmetropic or the ametropic eye, applies to it *only in a state of rest—only when it is adjusted for parallel rays*, and so for distance. That is to say, the eye is *emmetropic, if in a state of rest*, it focuses parallel rays exactly upon the retina; and it is *ametropic, if, in a state of rest*, it fails to do so.

It is common to speak of the emmetropic eye in a state of rest as being adjusted to infinity. It is needless to say that the eye never sees at that distance. What is meant is that as rays are *absolutely* parallel only when coming from an infinite distance the eye is perfectly adjusted to them only when adjusted to infinite distance. This fact in no way affects the statement, so frequently repeated, that rays coming from 20 feet distant are parallel enough for practical purposes, or for determining whether an eye is emmetropic or ametropic. A distance of 20 feet is far enough, in practice; but in theory, to be absolutely exact in a mathematical sense the expression infinite distance is correct.

*Accommodation.*—We now turn from the eye at rest to the eye *under tension* or *at work*. As just indicated its work consists in the effort imposed upon the ciliary muscle while increasing the refraction of the crystalline lens. This lens is enveloped in a capsule connected with the suspensory ligament (zone of Zinn) which, in turn, is attached to the ciliary muscle. When the muscle is at rest the ligament draws upon the capsule so as to compress and flatten the lens, causing it to assume its thinnest form. By its contraction the ciliary muscle

releases the capsule, to a greater or less extent, from the compression exerted by it upon the crystalline lens, and thus the latter is allowed to assume that more convex form toward which its elastic nature inclines it. As a result it becomes thicker, and so of greater refractive power, in proportion as the ciliary muscle contracts. Likewise, in proportion as the object examined approaches the observer, after coming within 15 or 20 feet, the effort of the ciliary muscle is increased to permit the corresponding increase in the thickness of lens and its consequent refraction, rendered necessary to see the object clearly. This power to accommodate or adjust its vision to different distances is called *accommodation.*

The accommodating power of the eye, whose process, as described above, accords with the best authorities, is a marvelous provision of nature, without an analogue among mechanical devices. Still, similar effects are produced with instruments, though the process is dissimilar. If an opera or field glass is drawn out to its full length it may be said to be adjusted to distant or quite distant vision. By gradually drawing in its tubes it may be accommodated successively to different nearer distances.

*Static refraction* and *dynamic refraction* are convenient expressions used by some to distinguish between the two kinds of refraction above mentioned. As the word static means standing still it refers to the refraction of the eye at rest. The word dynamic implies force and so refers to the eye at work or under tension, when exercising its accommodating energy.

*Amplitude of Accommodation.* — By amplitude of accommodation we mean the difference between the minimum, or static, and the maximum dynamic refraction of the eye, by which is shown the extent of its capacity to increase its refractive power. Hence the rule to determine amplitude of accommodation is, *subtract its minimum from its maximum refraction.*

The extent of this visual energy is indicated by refractive numbers, dioptric or inch, whichever the system is that is used to express the static and dynamic powers of the eye.

Visual amplitude covers a distance or range of accommodation at the extremes of which are situated two optical points. One is called the *near point* (punctum proximum), because it is the nearest point to which the given eye can be accommodated. The other is called the *far point* (punctum remotum), because it is the farthest point to which the given eye can be adjusted. As the emmetropic eye at rest is adjusted to infinite distance its far point is said to be infinity. The following sign ($\infty$) is used in mathematics as the symbol of infinity. The fact that an eye is ametropic instead of emmetropic does not necessarily diminish its amplitude of accommodation; it simply locates the space lying between the near and far points closer to or farther from the cornea, according as the eye is myopic or hypermetropic. Hence, as the near point is nearer in a myope than an emmetrope, the far point is likewise nearer in the former than in the latter. Conversely, as the near point of a hypermetrope is farther than the near point of an emmetrope, the far point of the former is farther than that of the latter. Thus, while the far point of the emmetrope is at infinity that of the myope is less, and that of the hypermetrope greater, than infinity.

If we let *a* represent amplitude of accommodation, and *n*, near point, that is, the refractive power necessary to accommodate for the near point, and *f*, far point, or power required to adjust to far point, we have the equation $a=n-f$. The effect of accommodation being the same as that produced by a convex lens the amplitude of accommodation in a given eye is measured exactly by a lens just strong enough to make rays, without accommodative effort, enter the eye from the near point as if

coming from the far point. If the near point is located and the accommodating muscle then paralyzed this may be shown very easily and accurately by using that convex lens which gives distinct vision at the near point. But without paralyzing the ciliary muscle we may determine the amplitude of accommodation in the following ways:

In emmetropia, find the nearest point at which the patient can read fine print. Suppose that is 8 inches, then an 8 inch lens or its equivalent, 5 D, measures the given amplitude. Again, the strongest concave lens that enables an emmetrope to see a distant object distinctly, also measures the amplitude of his accommodation.

In hypermetropia, you can first make the eye artificially emmetropic with a convex lens, enabling it to see at a distance without accommodation. Then by locating the near point while this lens is before the eye we can determine the amplitude of accommodation the same as in emmetropia. Or, we can determine the near point with the naked eye, and then by adding to the lens whose power is indicated by the distance of the near point the lens which measures its hypermetropia we shall get the measure of its amplitude. To illustrate, suppose the near point is 10 inches, indicating a 10 inch or 4 D lens, and the hypermetropia equals 1 D, then the amplitude equals the sum of these two, viz.: 5 D.

In myopia, on the contrary, we subtract the lens enabling him to see at a distance, from the one indicated by the near point. If the near point is 5 inches, equivalent to an 8 D lens, and his myopia equals 3 D, then his amplitude is their difference, 5 D.

*Recession of Near Point.*—The near point is nearest in childhood and gradually recedes as age advances. This would seem due solely to the diminishing elasticity of the crystalline lens, and not, even in part, to any varying

vigor in the accommodating muscle. If reduced vigor in the muscle helped to account for it, as some have supposed, the near point could hardly be expected to recede with such regularity. It might actually cease to recede and even return toward the eye in middle life, as the muscular system reaches its maximum at that age.

The following table shows the location of the near point in emmetropia at different ages. Authorities differ somewhat in some of the numbers. We have followed Fenner:

| AGE. | | NEAR POINT. |
|---|---|---|
| 10 | = | 2¾ inches. |
| 15 | = | 3¼ " |
| 20 | = | 3¾ " |
| 25 | = | 4¼ " |
| 30 | = | 4½ " |
| 35 | = | 6½ " |
| 40 | = | 9 " |
| 45 | = | 12 " |
| 50 | = | 18 " |

Below we give a table showing the amplitude of accommodation at different ages resulting from the recession of the near point.

| AGE. | AMP. OF ACCOM. |
|---|---|
| 10 | 14 |
| 15 | 12 |
| 20 | 10 |
| 25 | 8.5 |
| 30 | 7 |
| 35 | 5.5 |
| 40 | 4.5 |
| 45 | 3.5 |
| 50 | 2.5 |
| 55 | 1.75 |
| 60 | 1. |
| 65 | 0.75 |
| 70 | 0.25 |
| 75 | 0.00 |

The far point remains the same till about fifty. From that time forward it, like the near point, gradually recedes, caused no doubt by the flattening of the lens, by which the emmetrope acquires what may be called progressive hypermetropia, while the myope becomes less and less myopic.

At 75 the amplitude of accommodation is reduced to zero, showing a loss of all accommodating power. The near point has receded till it has become identical with the far point. This fact renders emmetropes and hypermetropes more and more dependent upon glasses as age advances. On the contrary myopes often become less and less dependent upon them and even indulge the flattering, though erroneous fancy, that they are exceptions to the rule that all persons reaching advanced years need glasses at some time of life. With a slight degree of myopia a person may get along in youth without glasses, though not without injury to vision, and then because the near point has receded in later years to the normal distance, and he seems to see more easily than ever, he mistakenly imagines that he never needed glasses and perhaps never will.

*Presbyopia.*—The gradually diminishing power of accommodation accompanying advancing years finally reaches a point at which it begins to be known as presbyopia. Being caused by the gradual hardening of the crystalline lens, and proportionate weakening of the ciliary muscle in its power to modify the form of the lens, (a normal change resulting in the recession of the near point as explained), the treatment of presbyopia falls appropriately under normal sight. Contrary to a notion sometimes indulged, this hardening process is perfectly natural, as much so as the increasing brittleness of the bones accompanying age, and so is a normal feature of emmetropic or normal vision. Of course it will not be

inferred that this change is not characteristic of abnormal sight also; all eyes are subject to it. The single point to be kept clear is that the process itself is not abnormal.

The present seems the proper place to treat not only presbyopia but other leading features of normal sight. While doing this it will be remembered that the primary meaning, in an optical sense, attached to the term normal relates to the length of the eye in comparison with its refractive power. In this regard there is no lack in the emmetropic eye, even after presbyopia has set in.

The word *presbyopia* means aged or old sight. As the eye gradually loses its power of accommodation, in the progress of the hardening process, the reading is pushed farther and farther from it. Ordinarily it becomes inconvenient to read at a distance beyond 14 or 16 inches. Not only does the distance become inconvenient, but it renders the illumination insufficient for the reduced acuteness accompanying age. When the near point has receded 8 inches, equivalent to 5 dioptries, it is customary to regard presbyopia as beginning. The selection of this point is arbitrary, and yet it is not without reason. At about this point the individual first begins to realize his need of glasses, because of the reduced accommodation, acuteness and illumination, and also the increased and increasing distance at which he must hold his reading to see it comfortably. Moreover these conditions are apt to become manifest and often painfully evident to the individual soon after he passes the meridian of life (at about 40), and this fact suggests and justifies the term presbyopia.

In continued close use of the eye its accommodative power is only about half as great as the maximum power of accommodation to which it can temporarily attain. It soon becomes exhausted under its maximum tension. Accordingly if the maximum is 5 D, equivalent to 8 inches, then under continued close use of the eye the object

examined will need to be held at about 16 inches. If the maximum is $5\frac{1}{2}$ D, equal to 7 inches, the object or reading may be held at 14 inches. To prevent any farther removal of reading or reduction of acuteness, convex glasses must now be used, as stated, even for emmetropic vision. And so presbyopia is said to commence at this time, although the process that has developed and will continue to increase it, began its active operation in childhood, as already shown.

The gradual change in the eye noted above progresses with such regularity as to furnish a criterion to the age where the vision is perfectly normal. The imperfection of the average eye, however, materially affects the value of this law as a guide. Still, it is common to give a table showing the refractive powers adapted, according to this law, to different ages, in case the vision is emmetropic. Most tables are based upon Donders with but slight variations. Perhaps Landolt varies more than anyone else, and, as we think, with good reason. Our table is based upon his with a few modifications or rather additions:

| Age. | Dioptries. | | Inches. |
|---|---|---|---|
| 40 | .25 | = | 158 |
| 45 | 1 | = | 40 |
| 48 | 1.50 | = | 26 |
| 50 | 2 | = | 20 |
| 53 | 2.50 | = | 16 |
| 55 | 3 | = | 13 |
| 58 | 3.50 | = | 11 |
| 60 | 4 | = | 10 |
| 63 | 4.25 | = | 9¼ |
| 65 | 4.50 | = | 8¾ |
| 68 | 5 | = | 8¼ |
| 70 | 5.50 | = | 7 |
| 73 | 5.75 | = | 6¾ |
| 75 | 6 | = | 6½ |
| 78 | 6.50 | = | 6 |
| 80 | 7 | = | 5½ |

The equivalent refractive powers in inches, though not exact to a mathematical nicety, are substantially correct, as near so as possible without resorting to needlessly small fractions—near enough to save all danger of practical error.

*Symptoms of Presbyopia.*—To determine if a patient is presbyopic inquire concerning symptoms as follows:

1. Consider his age. Under some circumstances presbyopia makes its appearance previous to the fortieth year. This may result from premature old age induced by sickness, by overtaxing one's energies, by deficient nourishment of the vital forces, particularly those involved in the exercise of visual power. Likewise, when other optical defects are associated with presbyopia it is common for it to show itself at an earlier period than otherwise usual. In such cases as the above, presbyopia is liable to occur almost anywhere along in the thirties. When contrary conditions exist, the body being vigorous and the vision normal, one may not feel the need of glasses till about forty-five, or even older. But forty seems the safest standard to adopt as the average age at which the emmetrope, as a rule, will begin to need glasses to correct his presbyopia.

2. Inquire if the patient's eyes are soon wearied, particularly when used in artificial light or on fine work. These are among the earliest symptoms of presbyopia.

3. Notice if the patient inclines to push his reading beyond the natural distance convenient and proper for holding it. The recession of the near point, from which presbyopia results, is the cause of this.

4. Observe if at the same time he objects to fine print and instinctively turns from it to coarser type. The added distance reduces the size of the image on the retina and

also the illumination, whereas advancing age and diminishing acuteness require that both be increased. Convex lenses accomplish this by enabling one to bring the reading nearer.

5. Note the significance of expressions used by the patient in describing his experience. He may remark that he has "always had excellent sight until recently," or that his "eyes never began to fail till a year or two ago," or that "print which he used to read easily now begins to blur and look dim no matter what distance he holds it," or that "night work or over work has injured his sight." This tendency to assign as a reason for poor sight some other than the chief cause is often due to a lack of knowledge, and sometimes to a disposition to ignore the fact that one is getting old enough to begin to develop presbyopia.

True, some of the above symptoms reveal themselves to a greater or less extent in other optical difficulties also because similar ocular weaknesses are common to different defects of sight. But each defect has peculiar characteristics of its own. When these are all understood each defect is readily distinguished. The specialist detects the manifestations of presbyopia at once, and likewise any malformation present.

*Remedy.*—The remedy for simple presbyopia is as invariable as its presence is unmistakable. It is corrected by the use of spherical convex lenses. It is usually preferable in making a test to begin with a weak lens and gradually pass on to the trial of stronger refractive powers. The distance one wishes to hold his reading, or the character of one's employment and the distance at which his work must be placed, should be known, that the tests may conform to these requirements. The weakest lenses that give one clear, comfortable vision at the proper

distance, should be selected. The average reading distance is 14 or 15 inches. After testing each eye separately the two lenses selected should be tried together sufficiently to see if the eyes work in harmony while using them. Fitting the eyes together is indispensable to the securing of the most perfect binocular vision possible. If the eyes refuse to work in harmony because of too great a difference in the powers of the lenses, the best rule is to see that the stronger eye is correctly fitted, and then modify the power before the other eye till the refractive powers of the two lenses are near enough together to secure harmonious binocular vision. This rule should be remembered in fitting all optical defects.

Glasses should be worn as soon as their need is felt and with the steady advance of presbyopia their power should be steadily increased. The advice of Donders is worthy of mention for the sake of those who are willing to have two pairs. One's feeling that he needs glasses will naturally begin in artificial light. He advises that as soon as one begins to feel the need of a stronger pair at night he should take his former pair for use in day-time:

Even though quite confident that the only symptoms present are presbyopic. it is important to test every patient for distance first, lest some error of refraction like hypermetropia or myopia escape the attention.

One may verify his reading test as follows: Subtract from a lens of eight inches, representing the proper near point, a lens representing the actual near point. The difference will show the lens one needs to correct his presbyopia. If this corresponds closely to the test made the latter may be supposed to be right. This assumes that the near point desired for constant reading is 16 inches. But suppose it should be 14 inches instead of 16. Then 7 inches instead of eight should be taken from which to subtract the lens representing the actual near point. Again if the work is to be held at about

18 inches in constant employment a 9 inch lens should be taken from which to subtract the lens representing the actual near point.

*Binocular Vision.*—Vision with one eye is called monocular; with two eyes, binocular. Thus far we have described only those features of the eye which may be illustrated by reference to monocular vision. But the two eyes sustain an important mutual relationship which should be understood. Larger advantages are secured by binocular vision than we are apt to suppose. Monocular sight is indeed invaluable, but he who has the use of only one eye suffers an incalculable loss. In normal binocular vision a separate image of the object seen is formed upon the retina of each eye. In the main these images are alike, and yet there is a significant difference between them, due to the differing stand-points from which the two eyes observe the same object. To illustrate, let the object be a card of test type held vertically before you with one edge toward, and the other from, the face, and midway between the eyes so that the plane of the card bisects the body perpendicularly on a line with the nose. Close the right eye and the edge and left side of the card are seen; close the left eye and the edge and right side are seen. The edge and both sides are seen when both eyes are open, but both sides are seen by neither eye alone. In like manner some portions of an object will usually be seen by one eye and concealed from the other, especially if it is solid. Consequently the two retinal pictures are not exactly identical. They supplement each other. And yet double vision does not result. In some mysterious way the two images are fused in one. Various theories have been suggested to account for this. Perhaps the most prominent is that involved in what has been called the law of identical retinal points. It assumes that "for each point of one

retina there is on the other a corresponding point," the result of which is fusion of the two images. This fails to account for those supplementary points in the two pictures between which there can be no correspondence or duplicate relationship because they represent antipodal sides of the object which are respectively concealed from one eye and revealed to the other. No hypothesis yet mentioned affords a full and satisfactory account of this fusion of the images.

The practical benefits of fusing or blending the images are manifest. One is that of single vision or seeing singly instead of double, as already stated. Another consists in the ability secured to appreciate solidity in objects. Length, breadth and thickness are all brought into view as is not possible to monocular vision. The stereoscope illustrates this, as antipodal parts or sides of the picture are in its use respectively revealed to each eye alone, and thereby solidity of appearance secured. Distances and sizes of objects are likewise more accurately determined with two eyes than one. The following paragraph from Fenner states some of the advantages of binocular vision very happily: "Persons with but one eye perform delicate manipulations slowly and hesitatingly, and are liable to commit errors of judgment. Those who have recently lost an eye, soon learn this by experience. In attempting, for illustration, to pour water from a pitcher into a goblet, they often miss the glass. Anyone can easily appreciate the difficulties such persons experience in correctly estimating the distance and position of objects, by taking in his hand a pencil, and, after closing one eye, attempting to quickly place the point, held vertically, on a small spot on a table. He will in most of his efforts fail in the attempt, but if his hand be moved slowly, so as to give him time to correct errors of judgment, the point of the pencil will fall on the designated spot. With a single eye, we can accomplish

very good and useful results, but with two, our judgment is more quickly formed, and with a much greater degree of accuracy."

*Convergence.*— Normal binocular vision involves the convergence of the two eyes. When looking into distance the axes of the eyes are parallel or practically so. When looking at an object near by these axes turn toward each other. The nearer the object the greater this convergence. When the object is situated at any distance less than 15 or 20 feet the eyes' accommodation also is called into exercise, and the nearer the object the greater, as already shown, is the accommodative effort required, as well as the effort of convergence. The convergence and accommodation are thus seen to be intimately associated and to work in conjunction. The exertion of either brings the other into exercise. If accommodation be adjusted for a reading distance of 15 inches the axes of the eyes will be converged to a point at that distance. A child whose accommodation can be adjusted to a point within three inches of the face must converge its eyes sufficiently that both axes may be fixed on a point at the same distance, and this requires a high degree of convergence. Whether the associated activity of accommodation and convergence is wholly due to the demands of experience or partly also to the physiological character of the eye has been regarded as not quite settled. At any rate it is almost impossible to exert the accommodation without converging the eyes, and *vice versa*. Yet experiments show that at least within limits these two efforts may be dissociated. The convergence of the eyes is brought about chiefly by the internal recti. The harmonious action of the muscles of rotation is necessary to control the direction of the eyes. Strabismus or cross-eye, and the consequent diplopia sometimes following, result from inharmony between them. Attention to these defects will be given in a future lesson.

Notwithstanding the value of convergence in binocular vision, seeing and locating an object correctly is largely due to experience, as expressed by Harlan: "The correct interpretation of the impressions received by sight is after all, to a great extent, a matter of practice and education, with the assistance of the sense of touch. This is proved by numerous observations made upon persons who have been born blind, and whose sight has been restored, or rather acquired, by surgical operation. None of these persons have shown any indication of an instinctive use of their new-found sense: all have had to learn to see. None could distinguish form or distance, or could recognize at first, by sight alone, even objects that had been familiar to touch for years. Some seemed to find their first experiences painful rather than pleasant; and it is related of one who had earned his living as a street musician, and had gone about the town alone for years, that he became confused and lost himself when his eyes were opened, and had to beg some one to lead him home."

## LESSON VI.

### Ametropia or Abnormal Sight.

*Ametropic Vision.*—Having considered various features of emmetropic vision or normal sight, we now pass to the consideration of ametropic vision, or abnormal sight. As the eye is called emmetropic when the parts upon which vision depends are normal in construction and relations, it is naturally called ametropic when any of these normal features are absent. The privative letter "a" in the word ametropic indicates absence or negation,—in this case absence of measurement necessary to constitute a normal eye. It has been objected to the term ametropic that it sounds too much like emmetropic, so much so as to make its use confusing. We recognize the force of the criticism, but the fault is inherent in the language, which we are not at liberty to reconstruct. The fact admitted emphasizes the importance of distinct pronunciation of terms as the only remedy at hand.

Ocular measurements may be defective in different ways, and so there are several kinds of ametropia. If the eye is too short in its antero-posterior diameter, *i.e.*, from cornea to fundus, we have one species of ametropia; if too long, we have another species. Defects in the refracting media are also classed under ametropia. They produce evil results like those caused by defects in the length of the eye. A cornea that is too flat will affect vision the same as an eye that is too short. Insufficient refractive power in the lens or humors of the eye will produce the same result. The causes in the above eyes differ, but the effect in each case is the same, viz.: a convergence of the rays toward a point beyond the retina. On the other

hand, where the cornea is too convex, or the other media have excessive refractive power, an evil result will follow, the same as is produced by too long an eye. There will be an excessive refraction of the rays of light. Though the causes just mentioned vary, the consequence common to each case is that the rays are converged to a point inside the retina.

Thus, while it must be remembered that refractive errors are due in the main to defects in the length of the eye, let it not be overlooked that corresponding evils may result, as just indicated, from defects in the media. The caution is hardly necessary, for earlier authorities assumed that refractive anomalies were uniformly attributable to defects in the media: there seemed to be little or no thought of the extent of evil resulting from malformations in length of eyeball, whereas later investigators agree that this is the chief cause of errors in ocular refraction. There is one defect, however, that is entirely due to errors in the refracting media. It is caused by a variation of convexity, and a consequent inequality of refraction in different meridians of the eye, and is known as simple astigmatism. This assymetry, *i. e.*, lack of symmetry, in media may be associated with malformation in length of eyeball. A form of compound ametropia will then result, known as compound astigmatism.

These malformations in eyeball and media, included under the general head of ametropia, are divided into four distinct classes, known as hypermetropia, myopia, simple astigmatism and compound astigmatism. Each class will receive separate attention in the following lessons. Before entering upon their separate treatment a few general observations should be made having more or less reference to them all. This general discussion of certain underlying principles in optics will help to an easier and clearer comprehension of the nature of these malformations.

*Illustrative Principles in Refraction.*—We noticed in a previous lesson that the production of a picture is dependent chiefly upon three factors, viz: the relative position of, first, the object to be pictured, second, the refracting medium or media, and third, the screen or retina. When the refracting medium is elastic, like the crystalline lens of the eye the application of these principles will be modified by that fact. Hence we can apply them only where the refracting medium is rigid, as in an artificial lens, and thus illustrate the eye when free from the exercise of its accommodation.

Suppose the above three factors are so situated that object and screen occupy respectively on either side of the lens the positions of conjugate foci. A picture of the object will then be thrown exactly upon the screen, for the point where the latter stands is the focal point of the lens, the precise place to which its refractive power converges the rays. Bearing in mind that the picture is distinct only when formed at the focal point of the lens, let us consider the effect of varying any of the three factors mentioned, and notice how the malformations of the eye may thus be illustrated. In our illustrations let the conjugate focal point occupied by the object be twenty feet or more in front of the lens, that the rays from it may impinge upon the lens or other refracting media on practically parallel lines. Then the conjugate focal point occupied by the screen will be the principal focus of the given lens. Now suppose that while object and lens remain stationary the screen is removed towards the lens. Then the distance from lens to screen will be too short. The rays will be converged toward a point beyond the screen instead of upon it. In consequence the picture upon the latter will be indistinct. This illustrates the condition of the hypermetropic eye. It is too short. The retina is too near the refracting media. The point toward which the rays tend to converge lies beyond the

retina, and therefore the picture upon the latter is more or less imperfect.

Again, let the screen be returned to the conjugate focus first occupied. Now suppose a weaker convex lens is substituted for the lens first used. The rays will be insufficiently refracted and will in consequence converge again toward a point beyond the screen, the same as when the screen was brought too near the lens. This illustrates the defect of the eye when there is insufficient refractive power in the media. It also illustrates how abnormal shortness of the eye and insufficient refracting power in its media produce the same result—a convergence of the rays toward a point beyond the retina.

Now let the converse supposition be made, that while object and lens remain stationary the screen be removed farther from the lens, i. e. beyond the conjugate focal point first occupied. Then the distance from lens to screen will be too long. The rays will be converged to a point inside the screen, instead of upon it. In consequence the picture upon the latter will be indistinct if not invisible. This illustrates the condition of the myopic eye. It is too long. The retina is too far from the refracting media. The point to which the rays converge lies inside the retina, and therefore the picture npon the latter is more or less imperfect.

Again, let the screen be returned to the conjugate focal point first occupied. Now suppose a stronger convex lens be substituted for the lens first used. The rays will be over refracted and will in consequence be again converged to a point inside the screen, the same as when the screen was removed too far from the lens. This illustrates the defect of the eye where there is excessive refractive power in its media. It also illustrates how abnormal length of eye and excessive refractive power in its media produce the same result,—a convergence of the rays toward a point inside the retina.

To restate the above points in a single utterance as applied to the eye: If the retina is abnormally near the refracting media the focal point of the lens will be beyond the retina; if the retina is abnormally far from media the focal point will be inside the retina. Likewise, the focal point will be, if the media are of insufficient refractive power, beyond the retina, and if of excessive refractive power, inside the retina. When there is no abnormality in either length of eye or refracting media the focal point will fall exactly on the retina, making vision normal, and the picture distinct.

Once more, let us return to our original supposition, only let us substitute in place of the spherical convex first used a cylindrical convex lens of like power. If the screen stands at the conjugate focal point first occupied all rays will be so converged as to fall exactly on the screen, except those passing through the axis of the cylinder. These latter will tend toward points beyond it, causing defects of refraction on the angle at which the axis of the cylinder is set. The axis may be set at 90°, or 180°, or at any intermediate angle. This illustrates the astigmatic or cylindrical eye. Such an eye may be normal except in one meridian, on which meridian or angle there is insufficient refractive power. And an eye may be defective in more than one meridian. One meridian of a hypermetropic eye may vary from other meridians in the extent of its hypermetropia and thereby be rendered defective in a double sense. So a myopic eye may have one meridian varying from the rest in degree of myopia. Occasionally an eye will be hypermetropic in one meridian and myopic in another, thus rendering it not only defective in a double sense but in opposite directions. Astigmatism is thus seen to be of several varieties, all of which will be explained in their proper place.

The effect of the eyes' accommodation, as already stated, is to modify the application of the above illustrations, but only when the object is situated less than 15 or

20 feet from the lens, of course; at and beyond that distance their application is as shown. Their modified application within that distance will be suitably illustrated and explained as each malformation receives separate treatment.

The cursory treatment of these malformations altogether, in this lesson, may seem like anticipating their separate treatment. True, it may involve some repetition of thought, but there is little danger of the subject being too thoroughly developed or understood. The mutual relationship of these malformations is intimate. In a sense they illustrate each other inversely: for example, the laws governing far-sight and near-sight are opposites. Hence a comparative view of all together is almost pre-requisite to a correct understanding of each by itself. The situation of the optician is not unlike that of a general on the field of battle who discerns that the enemy's forces must be defeated in detail. Not only should he learn the character and location of each separate division of the enemy, as far as may be, but he needs to survey the field as a whole that he may take in the mutual relations of the several divisions and their capacity to support each other. Equipped in similar manner with requisite knowledge the optician may bear down upon the ocular forces of evil, confident of victory.

*Diagnosing Ametropia.*—The first important step in testing a malformed eye is to determine what species of ametropia it belongs to. Uncertainty at this point is a prolific source of error and confusion. Until this is determined all effort to fit the eye is haphazard work. The beginner in optics finds himself balked at this point in his progress, more, perhaps, than at any other. By failing to master the principles that differentiate the several species of ametropia, he goes on confounding one with the other and floundering around in the fog, when

everything ought to be clear as noonday. By a careful survey of the different forms of ametropia in their associated relations and contrasts he may escape this confusion.

In diagnosing ametropia notice, first, that the distance test is the one to be employed. Presbyopia, as heretofore explained, is fitted by the reading test. When, therefore, a case of simple presbyopia is met it is to be fitted by the near test with convex lenses, and set aside as having no particular connection with the subject here discussed, as the presbyopic eye is not malformed, while the ametropic is always due to malformation. When persuaded that the eye under examination has ametropia proceed to determine whether the malformation is hypermetropic or myopic in character. By placing the test chart at a distance of 15 or 20 feet and using spherical convex lenses hypermetropia may be detected if present. With their use the vision of the hypermetrope will be seen to improve. On the other hand by using concave lenses the vision of the myope may be improved and thus the presence of myopia detected. Similarly we may use cylindrical convex and cylindrical concave lenses to detect the presence of astigmatism. The test will also determine which class of cylinders the given case requires. By rotating the cylinder we can locate the angle of the defective meridian. If the eye needs only a plane cylindrical lens it has simple astigmatism. If it requires a cylindrical combined with a spherical lens it has compound astigmatism. When the general character of the defect is thus determined by the operator he is prepared to perfect his test, and prescribe the proper lens or combination of lenses required by the given eye. The various forms of ametropia are discussed in detail in subsequent lessons and rules laid down for fitting each.

## LESSON VII.

### Hypermetropia or Far-Sight.

*Hypermetropic Vision.*—A hypermetropic eye is insufficient in the length of its antero-posterior axis or in the power of its refracting media. Either its axial diameter is too short for its refracting power or else its refraction is too weak for its axial diameter. To define it comprehensively, in accordance with its fundamental character, we should say that the *hypermetropic eye*, being insufficient in axial or refractive measure, *lacks that correspondence between its length and refracting power which we have previously shown* to be the essential characteristic of emmetropic or normal vision. But remember, this insufficiency is found, as a rule, in its axial diameter rather than its refracting power. It occurs in the latter but rarely. In both cases, however, the insufficiency results alike in the hypermetropic condition, which consists in the principal focus being thrown toward a point beyond the retina. This fact, that the same resulting condition is due to the two-fold insufficiency mentioned, whether existing in the axis or media, simplifies hypermetropia in our understanding and treatment of it. In fact our method of correcting it tends naturally to suggest only one deficiency, and that one confined to the refracting media, instead of, as is the rule, to the eye's axis; and this misleading, though proper method of correcting it is possible simply because both forms of hypermetropia result in a common condition correctible by the one remedy which we should naturally expect to adopt if it consisted in deficient refraction alone. That both forms are corrected by the same remedy becomes obvious as soon as we reflect that where the eye is too short the retina is located so far

forward that parallel rays converge toward a focus behind it precisely the same as they do when there is deficient refractive power in the media.

Ocular malformations may be regarded from the standpoint of their conditions, or results, or causes, or essential character. One eminent author in endeavoring to define hypermetropia from these various standpoints has given no less than four distinct definitions. This is attempting to be needlessly precise, it seems to us, and is correspondingly inexact, betraying an erroneous conception of the essential requirements of a definition. The object of a definition is not to indicate all the conceivable conditions incident to the subject defined, but rather to point out those features whose limits uniformly determine its essential character. We greatly mistake if our definition does not possess the merit of doing just this. Still we have not neglected to call attention to conditions attending hypermetropia as incidental to it though not as parts of its definition. The term hypermetropia signifies excessive or over-measurement because of its effect on parallel rays in throwing their focus toward a point beyond the retina.

*Classes of Hypermetropia.*— A distinction observed above shows that there are two general kinds or forms of hypermetropia. The principal form is known as *axial hypermetropia*, being due to deficient length of axis. The second form we have chosen to denominate *medial hypermetropia*, as it is due to deficient power in the refracting media. Under this term we have grouped together several forms which some authors distinguish from each other according as they result from deficient power of refraction in the cornea, crystalline or humors. But as the media act together like a single convex lens the expression medial hypermetropia seems sufficiently

minute as a classification, except in a physiological treatment of the subject. If one cares to be more specific he can speak of corneal hypermetropia, crystalline hypermetropia, etc.

*Degree of Hypermetropia.*—The degree of axial hypermetropia in a given case depends upon the distance between its retina and principal focus. As these two points coincide in the emmetropic eye, the extent of their failure to do so in hypermetropia indicates its degree. That is to say, the distance from the nodal point (the refractive center of the refracting media) to the focal point of the given hypermetropic eye, as compared with the distance from the nodal point to the retina, indicates the hypermetropic deficiency of the eye. The proportion to which the former distance exceeds the latter shows the proportional deficiency of the eye. But these linear distances cannot be measured directly. Fortunately there is an indirect method of arriving at the deficiency owing to the law that focal distance and refractive power are equal to each other in an inverse ratio. Hence, if we can determine the refractive number or power necessary to add to the eye of the hypermetrope to make it equal the eye of an emmetrope, and thereby bring back its principal focus so it shall coincide with the plane of the retina, we shall have the number or refractive power which represents the deficiency in the given hypermetropic eye, and so can determine its proportional linear deficiency. For example, suppose a 2 D convex lens is just sufficient to bring up the eye of a hypermetrope to normal vision. It makes his sight equal to an emmetrope's, *i. e.*, renders it artificially emmetropic, by causing the principal focus to fall upon the retina the same as it does in an emmetropic eye. This lens, therefore, indicatates by its refractive power the degree of the

hypermetropia to be 2 D, equal to a 20-inch lens, and also shows that in the proportional length of the eye it is deficient $\frac{2}{40}$ or $\frac{1}{20}$. What part of an inch this is we can not tell, as we do not know the actual length of the given eye. We can only discover the proportional linear deficiency in the eye. Let us, for the sake of illustration, suppose that we know the axial diameter of a given eye. Suppose the axial diameter of the said hypermetropic eye be $\frac{9}{10}$ of an inch. Suppose a 10-inch lens brings its focus just back to the retina. This shows that its axial deficiency is $\frac{1}{10}$ of an inch, and so needs to be increased that much, or $\frac{1}{9}$ of itself, or else its refraction must be increased to that extent in order to secure normal or emmetropic vision. If we could increase its length $\frac{1}{10}$ of an inch and thus make it $\frac{10}{10}$, or 1 inch long, there would be no farther hypermetropia. Being unable to do this, we must increase its refraction by a 10-inch lens, as its present refraction is equal only to nine 10-inch lenses, and it needs to be ten 10-inch lenses, or their equivalent one 1-inch lens. This illustrates how we may determine indirectly the proportional linear deficiency in an axial hypermetrope, as well as directly the equivalent refractive deficiency.

In the same way the degree of a medial hypermetropia is revealed, but directly, of course, by the refractive power of the convex lens necessary to make it artificially emmetropic. The correcting lens required shows the extent of the deficiency in the refractive media and the consequent degree of hypermetropia present. The substance of it all is that the degree of a medial hypermetropia is accurately expressed in terms of refraction, and so is represented by the refractive power of the correcting lens, while the degree of an axial hypermetropia is expressed with exactness in terms of linear measure, and so must be deduced by inverting the refractive power of the correcting lens.

*Hypermetropia Compared with Emmetropia.*—The nature of hypermetropia becomes still clearer as we examine illustrations comparing it with normal sight. In the treatment of the latter subject we saw that the form and refraction of the emmetropic eye are such that parallel rays are refracted to a focus precisely on the retina, as shown in Fig. 11, A B and C D being converged to the point F.

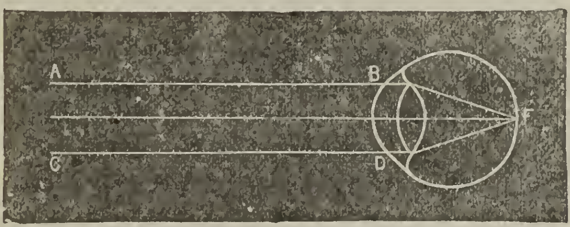


FIG. 11—EMMETROPIC EYE.

In the hypermetropic eye, on the contrary, parallel rays as R S and T U, in Fig. 12, are converged toward the point V, beyond the retina. The term "flat eye" is sometimes applied to it on account of its shape. The dotted line indicates what its shape would be if emmetropic.

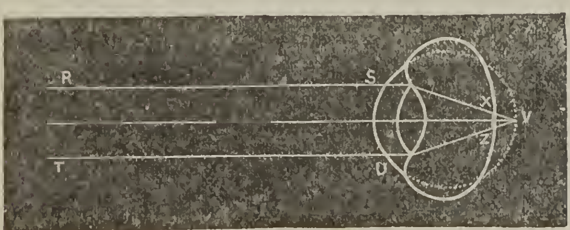


FIG. 12—EYE OF AXIAL HYPERMETROPE.

Whether the hypermetropic condition result from deficiency in length of eyeball or in refracting media the point V will be thrown beyond the retina, the distance

beyond being less or greater according to the extent of the deficiency. The focal point F, in Fig. 11, falling exactly on the retina will form a distinct image of the radiant point reproduced. Contrarywise, the focal point V, in Fig. 12, being beyond the retina, there are formed upon the latter circles of diffusion resulting in an indistinct image. In the cone R V T the diffused circle Z X gives a blurred picture of the point V. So all other cones radiating from the object seen will give blurred picture points, and in consequence the image of the entire object will be blurred.

As will appear in the following paragraph the accommodating power of the eye modifies to some extent the effects described above. The diagrams, however, illustrate accurately, as they are designed to do, the contrasted character of emmetropic and hypermetropic eyes so far as their static refraction is concerned, as may be shown by paralyzing the accommodating muscle.

*Hypermetropia Compared with Presbyopia.*—These two defects are liable to be confounded. Both being corrected by convex lenses may account for this, at least in part.

It will be recollected that presbyopia is due to a constant increase in the hardening of the crystalline lens. Presbyopia is thus seen to be a defect in the eye's dynamic refraction. Hypermetropia is quite different, being a defect in its static refraction. Yet both are corrected by a convex lens corresponding to the deficiency manifest. An artificial lens accomplishes this on the same principle as the dynamic power of the eye does, viz.: by increasing the refraction sufficiently to bring back the focus till it falls upon the retina.

In simple presbyopia there is no demand for lenses when looking at the far point, the eye being at rest and the focus falling on the retina. They are needed for the near point alone, for then only is the position of the

focus such as to require to be brought back to the retina. In hypermetropia, on the contrary, the position of the focus is always such as to require to be brought back to the retina in order to secure distinct vision. Hence the muscle of accommodation is called into constant exercise and the eye is subject to unceasing strain during waking moments, whether the hypermetrope is looking at a distance or near at hand. In some cases the process of innervation to the ciliary may continue in sleep, and a consequent exhaustion of the nervous system result. The involuntary persistence of the eye in trying to see distinctly renders this inevitable. To relieve this tension in distant vision, convex lenses of suitable power should be worn all the time. Where the hypermetrope is under 40 years of age the same lenses will usually answer for near vision also. But where presbyopia has set in, a stronger power is needed for reading glasses.

*Manifest and Latent Hypermetropia.*—As already implied, an eye's hypermetropia may be neutralized, to a greater or less extent, by its power of accommodation. In some cases this may be done completely; often it is possible but in part. To whatever extent it is accomplished, the result comes through increasing the convexity and consequent refraction of the crystalline lens.

The purpose of ocular accommodation in the economy of nature is to enable distinct vision to be fixed on objects near by—closer than 15 or 20 feet. But this power is called into exercise, as well, to assist hypermetropic vision in seeing at a distance. The extent of this assistance in distant vision measures the degree of hypermetropia in the given case. By placing a chart at the proper point for distant tests, and finding the strongest convex lens with which the hypermetrope can read the type distinctly, a definite degree of hypermetropia will be manifested. This is what is known as the *manifest*

*hypermetropia* of the eye. Its extent is measured by the refraction of the convex lens disclosing it. If a 2 D lens is the strongest that can be used, then the manifest hypermetropia amounts to two dioptries, or $\frac{1}{20}$ in the inch system. By relieving the eye, as far as possible, from all exercise of its accommodation, this lens relaxes the ciliary muscle and thus permits a reduction of the convexity of the crystalline. The degree of this reduction, being the measure of the lens employed, is the measure of the manifest hypermetropia of the given eye.

In some cases there is a degree of hypermetropia that cannot be made manifest in this way. There is a spasmodic effort or tense condition of the ciliary muscle which it persists in making no matter what lens is placed before it. The muscle, having formed the habit, refuses to cease exercising a part of its accommodating power, notwithstanding the lens is strong enough to relieve it of this necessity. The extent of this persistent accommodation, due to muscular contraction, measures what is called latent hypermetropia.

The nature of latent hypermetropia, as above explained, shows why it can not be detected and measured in the way manifest hypermetropia is. However, if the ciliary muscle is first paralyzed a convex lens will then suffice to measure latent as well as manifest hypermetropia. With a paralyzed muscle the requisite lens will expose the eye's total hypermetropia. If from the total hypermetropia we take what was found before paralysis to be the manifest, we shall have a remainder showing what is latent.

An ophthalmoscope, in skillful hands, may also be employed with more or less success to discover the amount of hypermetropia present.

A nice distinction, which it may be well to understand, though not important enough to deserve extended description, consists in classifying the manifest hypermetropia

of some eyes under different heads. Where one part of the manifest hypermetropia cannot be neutralized by the accommodation, and another part of it can be, two kinds of hypermetropia may be distinguished, if one cares to do it. Authors making these distinctions use terms to express them that strike us as not altogether happy. The most expressive language occurring to us would be to classify the former as involuntary manifest hypermetropia, and the latter as voluntary manifest hypermetropia. The usual terms for designating them are absolute manifest and facultative manifest hypermetropia. Donders makes a third distinction of only technical value called relative.

By using the weakest convex lens with which the hypermetrope can see distinctly at a distance, i. e., with his maximum acuteness, that part of his manifest hypermetropia which will be revealed is involuntary. He has no power to neutralize it. This weakest lens may be to some extent increased in its refraction without reducing the maximum distinctness of distant vision, until a lens is reached that is the strongest with which distinct vision is possible. The accommodation is repressed as the refraction of the lens is increased. The difference between these two lenses gives that portion of the manifest hypermetropia which we would designate voluntary, seeing it is under the control of the will.

Of latent hypermetropia, none is voluntary; if the distinction were called for all of it would naturally be denominated involuntary. It is to be noted that the diminution of accommodation due to advancing years causes latent hypermetropia to gradually disappear by being transformed into the manifest.

A mydriatic by paralyzing the muscle of accommodation will transform all the latent hypermetropia into manifest.

*Acquired Hypermetropia.*—We have seen that the far-point for emmetropia is infinity. When in advancing age the emmetrope's far-point begins to remove farther away, his vision is necessarily adjusted for a point beyond infinity, the same as original hypermetropia is. The result of this removal of the far-point developes what is known as *hypermetropia aquisita*, or in plain English, acquired hypermetropia. A flattening of the crystalline, due to senile degeneration, will account for it. In cases of this kind the patient has had no previous difficulty aside from his presbyopia, and so will have had no occasion for anything but reading glasses. But after the development of acquired hypermetropia he will need distance glasses also to insure maximum distinctness of distant vision, the same as original hypermetropia needs them, and for the same reason.

*Misconceptions about Hypermetropia.*—Hypermetropia is much more frequent than is generally supposed. The prevailing idea seems to be that it is less common than myopia. The converse is the fact. The habit and bearing of a myope are apt to expose his infirmity to others as well as to himself. The hypermetrope, on the contrary, may not know for years, and perhaps never, the nature of his trouble. He will experience weakness in his eyes, but may know it by no other name, not having the slightest suspicion that he is the victim of an ocular malformation, and that it may and should be corrected with lenses.

It is an error, likewise, to suppose that hypermetropic is better than emmetropic vision for distance. The fact that its refractive power is adjusted to a point beyond infinity shows that its accommodation is under tension at all distances, which involves constant strain and disadvantage. The emmetrope looks toward the horizon without accommodative effort, while the eye of the hypermetrope,

being under the continuous necessity of exerting its accommodation, soon tires. The nearer the object observed approaches the eye the greater the exertion and consequent weariness.

As previously stated, hypermetropia and presbyopia have sometimes been confounded. This may account, at least in part, for the later discovery by ophthalmologists of the nature of hypermetropia than of other common ocular defects. With only casual observance of it they assumed without farther investigation that it was equivalent to presbyopia. Donders says he sought in vain through the writings of the eighteenth century for evidence that hypermetropia was then understood.

It may be imagined that hypermetropia is developed by some error of habit. This is known to be true of some ocular troubles. But it is inexact to say it of hypermetropia: the only thing to be said is that the use of the hypermetropic eye unfitted with lenses will develop and aggravate those weaknesses that accompany it. But instead of hypermetropia being induced or developed by habit it is an arrest of development, whose usual origin is congenital. Infants are in a majority of cases said to be hypermetropic, "even many of those who afterward become emmetropic and myopic." There is a failure in the proportional development of the globe of the eye. Landolt's examination of the eyes of some of the lower animals becomes interesting in this connection. With the ophthalmoscope he examined the eyes of frogs, rabbits, cats, etc., and found them all hypermetropic. This seemed the more surprising, as he found their ciliary muscles imperfectly developed, which renders it probable that they cannot accommodate accurately for objects near by.

If we notice a person holding his book close to his eyes we naturally infer that he must be myopic and not

hypermetropic. This is not conclusive. Some hypermetropes bring the book very near the face, although the opposite is their tendency as a rule. Exceptions to the rule occur where the hypermetropia is of a very high degree. Almost inevitably such cases become more or less confounded with myopia.

Holding the reading so near, the hypermetrope's vision is necessarily disturbed by circles of diffusion.

Under the head of aberration we showed how different parts of picture points may fail to coincide upon the retina, but instead be distributed along the visual axis. Thus diffusion circles are caused and the result is a diffuse image. But this is likely to occur, to some extent, whatever the distance. Being unable to obviate it, he resorts to holding the book near by that he may thus counteract it, so far as possible, by increasing the size of the images. Practice in analyzing retinal images whose defects come from diffusion circles develops skill in recognizing the character of objects seen, despite the vague impressions due to the circles. The stronger light secured by holding the object nearer the eye affords still farther aid. Not only will it add intense illumination to the images, but will contract the pupils and thus restrict the circles of diffusion. Closing the lids partially will assist in accomplishing the same result; so also will shutting one eye and looking askant at the object across the bridge of the nose, since this intercepts the luminous rays in part. Recourse to various methods like this to improve vision may be indulged in by the patient with little or no apparent consciousness of the fact on his part.

Correcting the above and similar misconceptions may assist us to a negative diagnosis of an eye's defect, and therefore prove of great importance. Knowing what a defect is not we are much better prepared to determine what it is, and so announce a positive diagnosis. This is

a principle of general application to be observed by the operator in all his examinations.

*Evil Effects of Hypermetropia.*—Every defect naturally tends to provoke other troubles kindred in nature or association. Special attention is here called to those evil effects whose origin is traceable directly to hypermetropia. For example, headache is often a direct result of hypermetropia; and when not, the latter will aggravate the former. Even the indirect effects of ocular malformations, to say nothing of the direct, are sufficient to excite the most anxious interest of physicians, parents and teachers. At the birth of a babe it is the physician's first care to see that it is perfect in form and limb. Children would be saved untold suffering and sacrifice if similar care were exercised, at least as soon as they enter school, in examining their eyes, to see if vision is normal. There is special reason for this course in hypermetropia because of its liability to be confounded with weak-sight, asthenopia, whereby its victim may be so misled as to reach advanced years unconscious of the real nature of his trouble. The fact that hypermetropia is so common among children, as well as adults, makes the above precaution additionally important. No other ocular defect is so frequent and so apt to conceal its character and presence from its victim.

Something greatly dreaded in the family is the appearance of a cross-eyed child. In addition to the disadvantage to vision which it involves it is a serious disfigurement of the countenance. Now it is often possible to prevent the appearance of convergent strabismus, which is the most frequent variety, by correcting its cause. Ordinarily its cause is hypermetropia. So long as we neglect to correct the hypermetropia with suitable lenses the ocular muscles are subjected to

abnormal strain. If some muscles, being weaker, succumb to this strain more than others, the eye's axis is thrown out of its normal position and the eyes are crossed and distorted, producing convergent strabismus. By fitting the hypermetrope in childhood his eyes are relieved of this muscular strain, and strabismus avoided, in whole or in part. The greater the degree of hypermetropia the greater, obviously, its tendency to produce strabismus. In the lighter degrees fewer evil effects result since it is possible for the accommodation by overexertion to equal the task of supplying the refractive deficiency without such serious eye strain. It is thus seen that the presence of hypermetropia does not render certain the existence of strabismus, though it does give a predisposition to it. On the contrary, the appearance of convergent strabismus is a pretty sure sign of the presence of hypermetropia. In the language of Juler, "convergent strabismus in a child is an almost certain sign of hypermetropia." Diplopia, or double vision, also, when the result of convergent strabismus, is similarly traceable to hypermetropia. Weary, bloodshot, inflamed conditions often result from the strain imposed upon the muscles by hypermetropia, even with slight use of the eyes. It thus tends to develop asthenopia, as will be shown in the discussion of the latter subject, and an impairment of the nervous power of the optic nerve and fundus of the eye. The reading or work must often be pushed one side, to rest the eyes and wipe away the tears with which they are filled and dimned by the excessive tension. In some cases nervous twitchings betray the unnatural strain the eyes are undergoing. "In others again," to quote farther from Juler, "reading is always followed by headache, which occasionally is so severe that it is attributed to cerebral causes, and the subject of it condemned to spend his or her time in idleness, when the wole trouble might be removed by correcting the hypermetropia with suitable glasses."

The train of evils consequent and attendant upon hypermetropia as their primary, and when not primary, their aggravating cause is far more extended than even the specialists as a class have been accustomed to suppose. It is sufficient to suggest a single line of reflection to illustrate this remark and show its wide and important bearing. Physical functional activities depend chiefly upon the mind and muscles. The mind issues its edicts and the muscles execute the mandate. The action of the mind, called cerebration, must be correlated to the muscles or else the execution of the purpose will not follow. (Cerebration may be unconscious as well as conscious.) The question now arises, what is the connecting correlating link between mind and muscle? Science answers, it is the nerves that carry the nerve currents. When the muscles are normal they obey the will promptly and only healthy action is excited; when abnormal and refractory there is a resistance which constitutes an unhealthy reaction. This reaction is the cause of numerous maladies, styled nervous or sympathetic or reflexive, with various troubles whose origin neither victim nor physician may suspect.

An abnormal action or condition in the ocular muscles necessarily involves a serious reaction, and this refractory, reflex condition is a damage to the entire nervous system and through it to all the organs of the body, to the extent that they depend upon the nerves for the exercise of their normal functions. The brain is the great nerve center of the body. The refractory action of any of the muscles of the eye, whether the ciliary or the rotary, may naturally develop disturbance in the head, showing its symptoms not only in conscious eye strain and weariness, and in pain over the eyes and in the temples, but also in set headaches, often periodic, in dizziness or vertigo, in languid action of the brain and nervous depression. We are all aware that the digestive and assimilative organs

are very dependent upon the nervous system. We need not be surprised, therefore, to see that a disturbance of the ocular muscles will often produce nausea. The dealer has observed this when the patient has tried to wear a pair of glasses that did not fit. It may also occur even in cases when the eyes have been properly fitted. They may have been neglected so long that a proper fit creates such a decided change, a sort of muscular twist or pull, that it results in violent ocular disturbance (and eye strain for the time being), a strain necessary to bring the muscles back from abnormal to normal action. The patient, by wearing the glasses at intervals, will at length become used to them and be able to wear them without annoyance. Such results as these being matters of common observation, who can doubt that stomach troubles and the many ills that follow in their train may, and often do, have their origin in abnormal ocular conditions. When the correction of the refraction of the eye cures the ailment and does it so frequently as not to constitute an exception but to establish a rule, there is an end of argument. So many cases of this kind have been successfully treated by specialists that the optician ought no longer to neglect to avail himself of the advantages that will accrue to him and his customers if he practices his profession with an intelligent knowledge and application of the principle laid down.

When the muscular organs work harmoniously no one of them demands more than its allotted supply of nervous energy. Each receives just its share and fulfills its functions with ease. But suppose the defects of an organ create a demand for an excessive supply of nervous energy. Other organs must be impoverished in proportion, and so must work with increased friction. This will increase the aggregate demand for nerve force while it deranges and diminishes the supply. Reduced vigor will result. Lassitude follows, until "the grasshopper

becomes a burden," not because of age, not because "man goeth to his long home;" but because abnormal muscular action has lowered vitality and depleted the system. Many a nervous breakdown is due to hypermetropia. As much may be said of other ocular defects to be noticed hereafter. When recovery dates from the proper fitting of the eye, and no other remedy was employed, the testimony of the recovered patient is difficult to be gainsaid. The writer offers himself as a personal illustration and witness in support of the views here advanced.

*Diagnosing Hypermetropia.*— In proceeding to test a person's eyes let the operator first note by a casual glance the contour of his face and head. If he has hypermetropia, at least to a serious extent, the fact is frequently indicated to the observant specialist at once. By exercising his skill as a physiognomist the optician may often anticipate the general character of an ocular trouble. The hypermetropic eye will usually be found smaller, particularly its pupil, and possessed of greater mobility than other eyes. It may be deep set, although this is by no means an invariable rule. When it occurs partial reason for it may be found in the shortness of its antero-posterior diameter. The character of the eye being due to arrested growth it lacks plumpness or fullness of development. Corresponding to this deficiency of the eye there will often appear a lack of fullness in the face, inclining to flatness, and, at times, a dishing facial contour. This point is clearly stated by Landolt. "The relation between the conformation of the cranium and that of the eye is still more apparent in certain cases of asymmetry of the cranium and of the face. We very often meet people in whom one half of the head is visibly smaller than the other. One side of the forehead is only partially developed, receding, the cheek-bone more or less

flattened, and the diameter of the cheek less than that of the other side. The same difference is also found between the two halves of the palate. One side of the chin is, as it were, atrophied relatively to the other. The median line of the face is not straight, but slightly curved and turning its convexity toward the better developed portion, as if the latter tended by its more active growth to surround the other, which has been arrested in its evolution. Very frequently the measurement, or even simple inspection, of the cranium denotes a similar difference.

"In the majority of cases we find, corresponding to the less developed half of the head, the eye whose refraction is weaker (the smaller one), oftenest hyperopic, or presenting a higher degree of hyperopia, if this refractive anomally exists in both eyes. It is true that this rule admits of frequent exceptions, upon which we have never failed to insist. The general hyperopic type above spoken of, may also be wanting in cases of medium hyperopia, but the peculiar, characteristic form of the eye itself is almost never lacking."

Being questioned about his eyesight, the hypermetrope will be likely to speak of some symptoms referred to in our treatment of presbyopia. Hence the reader is invited to refer again to the symptoms there mentioned. Since both of these ocular deficiencies require the assistance of convex lenses, it is but natural that some similar symptoms should characterize each. While both, often after only a slight use of the eyes, will cause similar weariness in reading or close work, especially with artificial light, hypermetropia, particularly if it be of serious degree, will also cause weariness and discomfort even when the eyes are used in distant vision. Presbyopic eyes, we have seen, on the contrary, do not suffer overstrain in seeing at a distance. In near work both difficulties lead to turning the eyes from the reading, or closing them to give them

rest. In both the tendency is to push away the reading to an unusual distance in the effort to bring the focus back from the point of convergence beyond the retina to a place upon it, for both defects project the focus beyond the retina. In presbyopia, however, this results from the hardening of the crystalline lens; in hypermetropia, from deficiency in the axial diameter or in the refractive power of the eye. When the person is under forty years of age the presence of presbyopia is improbable, and so the existence of the common symptoms referred to above points to the probable existence of hypermetropia. "Probable," we say, since asthenopia, or some other defect might account for these symptoms. But whether the patient be under or over forty years of age, if hypermetropia is present that fact can be decisively determined by giving him a distance test with convex lenses. If a convex lens can be found that will enable him to see at 15 or 20 feet, or farther, more clearly than with the naked eye, he has either simple hypermetropia, or that in combination with some other defect. In the latter case the associate defect may occasionally be of such character as to disturb the certainty of one's conclusion. But careful attention to the nature and treatment of other defects will remove this danger in large measure. In other cases a tonic refractive condition, so called, will disturb the certainty of the conclusion. The customary contraction of the ciliary muscle, rendered necessary by the accommodation, may have become so firmly established and rigid that it will not relax sufficiently to render the convex lens of any service in measuring the power of the refracting media. The oculist overcomes this difficulty by administering a mydriatic, which relaxes the muscle by paralyzing it. The crystalline then returns to the static condition and the absolute refraction of the eye is readily determined.

*Fitting Hypermetropic Eyes.*—A proper diagnosis can hardly fail to indicate about what lens the given eye will require. From the foregoing paragraphs on diagnosing one may gather the general course to be pursued in fitting a hypermetrope. Experienced practitioners carry along together the two operations of diagnosing and fitting. For the sake of explicitness we have separated them, and now point out the order of the several steps to be taken when fitting.

The operator, as details are mastered, will properly abbreviate his procedure, and often vary it as experience may dictate, never failing, however, to apply at some stage of his process each principle involved. While not becoming less exact, in this way he will cultivate a greater freedom and independence. Our suggestions will probably seem to experts needlessly minute, but we cannot forget that beginners have the greater claim upon us, and for them one can hardly be too explicit.

1. Note all suggestive symptoms, including features, bearing of patient, etc.

2. Learn if the patient has been wearing glasses, and if so what kind, what refractive numbers, etc. Whether they have been too strong or too weak, or not suited in other respects, they will perhaps serve as a guide in making your test. If the hypermetrope has been imperfectly fitted we may naturally expect to find, in addition to ocular malformation, that his eye-sight has been more or less impaired; and the same will be true if he has gone without glasses long after needing them.

3. See that the lenses in your instrument or trial case are clean. Trial lenses easily get dusty and greasy.

4. Place your test card at a distance of about 20 feet, if possible,—15 feet will do if the operating room admits no greater distance. By directing the patient's attention

when being fitted to a distant object,—a sign, for example,—as well as to the test chart, the operator avoids the danger of over correction. Vision should be made satisfactory at long range: looking at various long distances will serve as a safeguard.

5. Instruct the patient to point out the line containing the smallest type which he can see distinctly with the naked eye—making test of a single eye at a time, and beginning usually with the stronger of the two eyes. This will give some idea of his vision. The other eye should be covered at the time, not closed. Closing it is liable to involve pressure upon the eyeball, and so a degree of unnaturalness.

6. Being certain that the patient is hypermetropic, begin with a weak spherical convex lens, say ½ dioptry, about No. 78 in the inch system. If it improves his vision you may know that you are on the right track. Then try a still weaker lens, it may answer equally well, and possibly better. If it does not, try ¾ D next. If this is better than ½ D, try 1 D, and then 1¼ D, and so on. Thus continue to increase the power of the trial lens so long as vision is improved. When a refractive number is reached which diminishes the clearness of vision, pause and repeat the comparison between it and the lens next weaker, also compare it with the lens next stronger. Several trials of this sort will enable the operator to settle upon the best lens for the given case. *The strongest number that gives the best vision is to be chosen.* Some operators increase the power of the test lens by a ½ D instead of a ¼ D at each step. This may facilitate the test, especially if the degree of the hypermetropia is considerable. The result may be reached more quickly. But the important thing is, after determining what three, or

possibly four, refractive powers include the number needed, to repeat the comparisons until satisfied which one this needed number is.

7. When both eyes have been separately fitted with lenses, binocular vision will generally be found satisfactory in using them, even if the refractive powers differ, at least if that difference is inconsiderable. But if it is sufficient to produce discomfort, the poorer eye must be refitted with a lens whose power comes near enough to the lens before the better eye to insure comfort to the wearer. Perseverance in wearing lenses of different power will often accustom the eyes to them, after a while, so that instead of the discomfort experienced at the outset they will become entirely comfortable and be altogether preferable.

8. Theoretically the strongest lens with which most perfect distant vision is attained when the ciliary is relaxed is the proper correction for the given case of hypermetropia. But sometimes the ciliary muscle becomes so fixed and rigid in its contraction that it refuses to relax fully. This prevents it releasing the crystalline sufficiently to determine absolutely the degree of the hypermetropia. In short, a considerable degree of hypermetropia remains latent, instead of becoming manifest. By wearing the lenses which give the best fit at the time they will be likely after a while to cause the muscle to relax its excessive contraction, at least in part. The eye will then accept a stronger lens. In some cases this method may be repeated until results entirely satisfactory are reached, where a mydriatic would otherwise be necessary.

9. Suppose a person having hypermetropia is so old as to have presbyopia in connection with it. Then fit him, invariably, for his hypermetropia first, and afterward

for his presbyopia, according to instructions heretofore given under that head.

In this last case the patient should have two pairs of glasses, one for distance and the other for reading, or else a pair of bifocals.

## LESSON VIII.

### Myopia or Near-Sight.

*Myopic Vision.*— Myopia was once thought to be the converse of presbyopia. It is, instead, as is now known, the opposite of hypermetropia. Accordingly we have but to reverse the forms of expression descriptive of hypermetropia in order to obtain descriptions of myopia. For instance, suppose the defect is in the media, then it will, in hypermetropia, consist of deficient refractive power in the refractive media, whereas, it will, in myopia, consist of excessive refractive power. Again, suppose the defect is in the axial diameter, then, if it is a case of hypermetropia, it is due to the eye being too short, whereas, if it is a case of myopia, it is due to the eye being too long. The fault of the myopic eye is thus seen to be that its refractive power or axial diameter exceeds the normal instead of falling below it as the hypermetropic eye does. Either the power of refraction is too strong for the eye's length or else the diameter is too long for the refractive power. Defining it comprehensively, we may say *the characteristic of the myopic eye is its excess of either axial or refractive measure, whereby it lacks that correspondence between the two which is necessary to emmetropic vision.* But notice, the myopia, as a rule, is found in excessive length of axial diameter, rather than excessive refractive power of media. But whether the excess is in the axis or in the media there is one common result, the myopic condition, in which the focus is formed within the eye, before reaching the retina. The fact that both forms of excess have a common result simplifies myopia as to our conception and correction of it. Correcting it with lenses naturally suggests one error instead of two, and that one

confined to the media, rather than the eye's axis as the rule is. This inference is possible, simply because both forms of myopia result in a common condition correctible by the same remedy — the very remedy that we should have to employ if the error occurred in the media alone.

Since both forms are correctible in the same way, with concave lenses, one might infer there was only one kind of myopia, instead of two, and that it was always a defect in the media, whereas, it is usually a defect in the eye's axis. That one and the same remedy will correct both forms of myopia we are able to see clearly, as soon as we reflect that where the eye is too long parallel rays must converge to a focus before reaching the retina, precisely the same as where there is excessive refractive power in the media.

*Classes of Myopia.*—The distinction made above shows that myopia is of two general kinds. It is known as *axial myopia* where it results from excessive length of axis. Where it is due to excess of refractive power in some of the media, we have, in the absence of any standard designation, called it *medial myopia.* We include under this expression several forms which some authors distinguish from each other according as they result from excessive refractive power in the cornea, crystalline or humors.

Inasmuch as medial myopia is exceedingly infrequent in comparison with axial myopia, the term used to describe it seems to us a sufficiently minute classification, unless one is treating in detail the physiology of the eye.

*Myopia Illustrated.*— Examining Fig. 13 will make plain the nature of myopia as compared with emmetropia and hypermetropia. Fig. 11, Lesson VII, shows that parallel rays are, in the emmetropic eye, converged to a focus precisely on the retina, while they are converged to a focus beyond the retina in a hypermetropic eye, as shown


FIG. 13—EYE OF AXIAL MYOPE.

in Fig. 12, of the same lesson. In the myopic eye, on the contrary, it being the converse of a hypermetropic eye, they are converged to a focus before reaching the retina. The rays, G H and I J, Fig. 13, unite in a focus, F, instead of converging on the retina where they need to meet to produce clear vision. The worse the myopia the farther from the retina will the focus be, and the more diffuse and dim will be the image. This explains why the myope cannot see clearly at any distance far enough away that the rays enter the eyes on parallel lines. In proportion as the object comes nearer than 15 or 20 feet there is a corresponding improvement in the myope's vision. This results from one of the principles of refraction. When the object seen is so near that the rays entering the eye are divergent instead of parallel, conjugate foci are formed. In proportion as the external focus approaches the cornea the internal one recedes from it, drawing nearer the retina. Thus the object may be brought so near that the focus and consequent picture will be projected upon the retina, and definite vision obtained, but as this nearness will be less than normal, according to the extent of the myopia, concave lenses are really needed for near vision as well as for distance. However, reading lenses may be dispensed with where the myopia is slight. The above facts account for the noticeable habit of near-sighted persons of bringing the reading near the face.

*Degree of Myopia.*—The distance of the focus from the retina, as formed within the eye, indicates the degree of myopia. This distance, though it can not be measured directly, may be determined indirectly, since linear distance may be expressed in terms of refraction. The distance from the nodal point to the focus shows the refractive power of the given myopic eye. The distance from the nodal point to the retina of the same eye shows what refractive power its axial diameter requires. Now, it is evident that these two refractive powers represent the respective distances from the nodal point to the focus and from the same point to the retina. And as the difference between these distances shows the excess of length in the axis, the difference between the respective refractive powers must show the excess of refraction in the eye. Now we can discover what this excess of refraction is by finding what concave lens will diminish the refractive power of the eye just enough to carry the focus on to the retina and thus secure clear vision. Suppose a concave lens of 2 D. will accomplish it. Then there is a myopia of 2 D., showing excessive axial length to that extent, or, as occurs in rare instances, a corresponding degree of abnormal refraction in the media. The principle here mentioned was discussed under hypermetropia, and so a passing reference is sufficient in this connection.

*Misconceptions about Myopia.*—The very term myopia reminds one of the early ignorance concerning its nature. There is, in myopes, a tendency to draw the eye-lids together in order to cut off circles of diffusion. This being observed, it was thought that the word myopia, which means to half close the eyes, would be a suitable designation. But inasmuch as it marks an accidental rather than a fundamental feature of the myopic eye, the term is not the most appropriate.

In the word hypermetropia, on the contrary, a term was adopted which suggests, instead of some incidental tendency, the fundamental nature of the defect it designates. Notwithstanding the word myopia fails to suggest the nature of the trouble it names, it has become so fixed in optical usage that it is not likely to be replaced by any technical word more suitable in significance, such as brachymetropia, which Donders recommended. The word "short-sighted" is quite exact in meaning, and for popular use, like "near-sighted," answers very well.

Some suppose the myopic eye superior in strength. A reason for this mistaken notion is that the myope, more readily than the emmetrope, distinguishes small objects, being able to bring them nearer his eye, the same as the stronger the lens a man puts before his eye, the nearer he can and must bring the object examined. As noted in the discussion of the subject, the size and consequent vividness of the retinal image are thus increased. Farthermore, the nearness of the object increases the quantity of light it reflects upon the retina. This increase in the intensity of illumination increases the distinctness of vision. The extra dilatation characteristic of the pupil of the myopic eye adds still farther to the quantity of light received by it.

By making himself artificially myopic with a convex lens the emmetrope may, by experiment, satisfy himself that the above facts explain the supposed superiority of the myopic eye. When by the aid of a lens his refraction has been raised to a power equal to that of a given myope, he will see by comparison that the myopic eye is really poorer than the emmetropic, its fancied superiority being only apparent. Its structure being abnormal this is what might be expected.

It has been assumed that age improves the myopic eye. So far as myopia of a high degree is concerned the supposition has little if any plausible support. In milder

degrees there are some changes consequent upon age which seem at first thought to justify the assumption. For example, the pupil of the eye contracts with age. This cuts off some of the circles of diffusion which annoy the myope when looking into the distance, and to that extent there is, incidentally, an improvement of the vision, but not of the eye.

The myope may, as age advances, become conscious of diminishing near-sightedness for another reason. And the natural inference will be that an improvement is taking place in the myopic structure of the eye. But it is a mistake. It is the presbyopic change of the eye which accounts for the improved vision. The principal focus fails, in myopia, to reach the retina, the eye being too long, and the rays, in consequence, being refracted correspondingly too much. But as presbyopia goes forward this over-refraction is reduced, and the focus approaches proportionately nearer the retina, the distance of the object examined remaining the same. The rays being less refracted, on the other hand, the object may be removed proportionately farther away without changing the situation of the focus. As a result the myope can remove his book to a greater distance, as age advances, and still read with no less ease than before. Not, however, because the eyes' myopic structure has undergone any improvement; the effects of myopia have simply been counteracted by the presence and progress of presbyopia. The superiority claimed for myopia is thus seen to be imaginary, being more than offset by manifest disadvantages, as will still farther appear under progressive myopia.

Now and then persons in advanced life are met who declare that they never needed glasses. Having always gotten along without conscious or at least serious inconvenience, they are unaware that what they utter is at best but a half truth. The simple fact is that they have had myopia of a low degree. Had they been sailors, or in

some other vocation rendering distant vision indispensable, their mistake would have been discovered. As it is there has been no call for their discerning distant objects with special accuracy, and so they have never been led to compare their own sight with that of persons of normal vision. Had this been done their deficiency would have been detected. Or, they may have failed to recognize, or refused to admit, the manifest proof of inferior distant vision on their part.

A striking illustration of these views is found in the following paragraph by Carter: "Landscape painters are the only persons to whom a small degree of myopia can be useful. I once accompanied a landscape painter on a sketching expedition, and after a time asked him whether he intended to omit a certain house from his drawing. He looked up with surprise, and said, 'What house? There is no house there.' I at once understood a curious haziness of aspect with which it was his custom to clothe distant scenery in his pictures, and which was greatly admired by many persons who mistook it for a skillful rendering of an uncommon atmospheric effect. In fact, it was only what the short-sighted man saw always before him; and I am sure he must himself have been greatly puzzled by much of the praise which he received."

Not being specially dependent on distant vision the persons under consideration, those with a low degree of myopia, may glance toward objects in the distance with no suspicion that others can see them better than themselves. As to reading, they have managed that well enough by holding the book a little nearer than others, and yet have not had to hold it near enough to make concave lenses indispensable, nor even to attract their attention to the fact that anything was particularly wrong with their vision. With advancing age they have needed to push their reading gradually farther away, but this having failed to remove the near point beyond 16 inches

before they were 60 or 70 years of age or older, they have never felt the need of convex lenses, and so have erroneously supposed themselves exceptions to the rule that sooner or later all persons need glasses.

Inasmuch as the recession of the near point beyond 8 inches, thereby practically removing the reading point for continuous use some 16 inches, is what necessitates the employment of convex lenses, and since the need of approximating the object unnaturally near the eye is what necessitates the use of concave lenses, it becomes plain why some seem never to need glasses. Their range of vision in reading is such that it does not in old age exceed about 16 inches, while it did not, on the other hand, bring the book so near in early life as to involve special discomfort. These explanations conduct to the conclusion that persons fancying themselves never in need of glasses are victims of a delusion, as well as of a degree of myopia which would have been benefited by the use of concave lenses. In looking at distant objects such eyes cannot escape some degree of deleterious strain, and would have been more or less guarded against its increase if concave lenses had been worn continuously for distance, and in many cases for reading also.

*Progressive Myopia.*—The natural tendency of myopia is to progress, though it is possible for it to remain substantially stationary. This progressive tendency is, naturally enough, common to most disorders. Its arrest, if at all possible, can be accomplished by none but active measures. In its structure the myopic eye is abnormal and disordered, not to say diseased, about which last characterization the authorities are hardly agreed. To us the term seems sufficiently justified, particularly by the progressive phases of myopia. An examination, especially of the posterior parts of the myopic eye, confirms this view. The serious fact about it is that it involves

injurious pressure upon the posterior portions of the eye. This may be explained in one or both of two different ways. The very form of the myopic eye may account for it. Because of its shape the shell of an egg bears the greatest pressure at its small end. The prolongation of the posterior pole of the myopic eye makes it similar in form, and so it suffers greater internal pressure there than elsewhere, and greater than that suffered by the normal eye. If the posterior coats, membranes and vascular tissues are thinner in the myope than in others, as is maintained, there must be not only greatest internal pressure, but also least power of resistance at that point. Thus, we see in the structure of this eye sufficient reason for the progressive tendency of its myopia.

The subject being of unusual importance to the myope, and to all who are called to advise or treat him, we make liberal extracts from those who have made its study a specialty. After reading the following paragraph from Donders one must feel that if that author's views on optics merit the large credence generally bestowed upon them, they certainly deserve great weight on the subject of progressive myopia, to which he has given such pains-taking attention. He says:

"The number of myopes most accurately examined by me amounts to more than 2,500. Each time the degree of myopia was accurately determined and noted. If, after months or years, the myope consulted me again, the determination was repeated. I thus came to the conviction that almost always the myopia is somewhat progressive, that such is the rule between the 15th and 25th years, and that the highest degrees often exhibit the greatest increase. I have never in the periods of youth or manhood proved diminution of myopia, except in the rare cases in which spasm of the accommodating system had temporarily increased it, and where, therefore,

anomaly, not simply refraction, but also of accommodation, was present. Even at a more advanced time of life, diminution of the degree of myopia seldom occurs."

Qualified by these extended observations he affirms that, "High degrees of myopia are less likely to remain stationary than slight degrees are; at a more advanced time of life they even continue to be developed, with increasing atrophy of the membranes. In youth almost every myopia is progressive; the increase is then often combined with symptoms of irritation. This is the critical period for the myopic eye: if the myopia does not increase too much, it may become stationary, and may even decrease in advanced age; if it is developed in a high degree, it is subsequently difficult to set bounds to it. At this period, therefore, the above mentioned promoting causes should be especially avoided. On this point I cannot lay sufficient stress. Every progressive myopia is threatening with respect to the future. If it continues progressive, the eye will soon, with troublesome symptoms, become less available, and not unfrequently at the age of 50 or 60, if not much earlier, the power of vision is irrevocably lost, whether through separation of the retina from the choroid, from effusion of blood, or from atrophy and degeneration of the yellow spot."

The following from Mittendorf is a most excellent condensation of the subject:

"Of the greatest importance is it to determine whether the myopia of an eye is progressive or stationary. As a rule, myopia may be considered stationary if it has not increased to any extent after the twentieth year, and is of slight or moderate amount, say, or less. In these cases we have no, or only a slight, posterior staphyloma, and there is no tendency to an increase of the myopia, because the sclera has become so hard and resistant at this age that it will yield only in exceptional cases. Myopia that progresses slowly is generally not called progressive; this

term is reserved for those cases where the increase is rapid and accompanied by slight congestive symptoms, such as local heat, dryness, and a dull, heavy sensation of the eye, sensitiveness to light, and even pain; photopsies and *muscae volitantes* are also mentioned as annoying symptoms by such patients.

"Myopia may be progressive only for a short space of time; this occurs generally between the twelfth and twenty-fifth year; after this it is more apt to remain stationary; but a more dangerous variety is the constantly progressive myopia; it depends upon a want of resistancy of the sclera and is apt to develop during puberty, and will increase steadily or in jumps, until the eye has lost most of its visual power: in many instances it will terminate in detachment of the retina or in cataract."

A slight difference between the above authors may be noticed, but it is only slight. Donders says that, "almost always the myopia is somewhat progressive," especially in early life. Mittendorf really implies as much, instead of the contrary, though he withholds the term "progressive" from "myopia that progresses slowly," and reserves it "for those cases where the increase is rapid."

*Causes of Myopia.*— Unlike hypermetropia, myopia is, properly speaking, not congenital. There are latent tendencies that predispose the victim toward it, however, and, naturally enough, these are hereditary. They provide its conditions. The proper statement, then, is, not that established myopia is born with the child, but simply the predisposition to it, and that afterward it comes as a natural development. Still, it must be admitted that sufficient ophthalmoscopic and other examinations of infants' eyes have not been made to remove the question entirely beyond the region of dispute. But leading authorities incline to the view here

adopted, and affirm that the controlling causes of myopia are due to civilization, citing in support of this position experiments such as will be shortly mentioned.

If by the expression, causes of myopia, we refer to the myopic condition, then our meaning is to be found in the eyes' axial and refractive defects, already explained. If our reference is to its origin, in so far as the latent tendencies are concerned, then we have in mind its predisposing cause. But if we are thinking of the influences in civilization that produce it, they constitute its *developing cause.* The former two causes having received previous attention, we now notice the developing causes found in civilization. This subject is abundantly illustrated by the examinations of Dr. Cohn, in Germany, Dr. Erisman, in Russia, and others, whose conclusions are freely quoted by our latest and best authorities.

There is in civilization what might be termed a microscopic tendency — a habit of life involving close and prolonged application of the eye at short range, as required by the studies of the scholar, the toil of the seamstress, and those higher grades of workmanship demanded in handling delicate fabrics, and constructing finely wrought pieces of mechanism and art where minute observation and continued concentration of vision are exacted. The ocular convergence which these employments necessitate is secured through the rotating muscles, whose tension when thus exerted involves a considerable internal pressure upon the tunics of the eyes. With congenital weakness of its tunics the eye readily yields to this pressure and becomes elongated posteriorly. This gives us the myopic condition developed — developed through the demands of civilization, demands for continuous work at short range or the reading distance.

Investigations in different countries have shown a smaller proportion of myopes among manual laborers than among students. And the percentage among the latter

has been found to increase regularly as you ascend from the lower to the higher graded departments of school and college life. The higher you go the longer continued and the more exacting the scholars' studies necessarily become. Even among outdoor laborers variations appear, which, when traced to their cause, are found to correspond to the classifications made above. Laborers who come from the schools are more myopic than others.

In examining 1,600 soldiers Seggel found only 2 per cent. of myopes among those recruited from the peasantry; 4 per cent., from common day-laborers; 9 per cent., from mechanics; 44 per cent., from merchants, printers, etc.; 58 per cent., from one-year volunteers, who came from young men that had enjoyed higher school advantages.

The foregoing conclusions are in general agreement with the observations of Tscherning upon male populations of the same age. Though there was a considerable difference in the number of cases of each class examined by him, doubtless his induction was sufficiently wide to verify the general laws believed to govern the question. Among some classes his examinations covered several thousand cases, and in all they extended into the hundreds. Among peasants, sailors, and day-laborers he found 2.45 per cent. of myopes; among various kinds of mechanics, 5.24 per cent.; among mechanics engaged in near work, 11.66 per cent.; among artists, engineers, and architects, 13.33 per cent.; among merchants, 15.76 per cent.; among professional men, 32.38 per cent.

Though the figures derived by these two examiners in testing similar classes do not correspond precisely, that may be accounted for by some variations in the extent or other features of their induction. It is enough that they settle satisfactorily the single point of importance, viz.: the general law of classification and progression from one class to another, which points to civilization as the developing cause of myopia.

The investigations of Bushbeck show that myopia is developed very noticeably among children employed in threading needles in the knitting mills. In comparison between children who both worked in the mills and attended school and their school-fellows who were not engaged in the mills, he found that the per cent. of myopes among the former was 5.4 per cent. higher than among the latter. This contrast was in no way due to unfavorable hygienic conditions, the investigator maintained. In conformity with the above facts observers are agreed that a smaller percentage of myopes is found in industrial than in other schools. In the gymnasium (the name for a grade of school in Europe next to the university) there were from 30 to 55 per cent. of myopes, while it ranged from 40 per cent. down to 20 in industrial schools.

Following up this line of investigation the statistics of Erisman show that the percentage of myopes is affected still farther and very perceptibly by the number of hours per day the scholars are occupied in school. School confinement for six hours a day developed 40 per cent. of myopes; four hours a day, only 29 per cent.; and with but two hours per day, it fell to 17 per cent.

Examinations of over ten thousand children were made in Germany by Dr. Cohn, of Breslau, who found that about 10 per cent. of them were myopic. He concluded not only that myopia increased regularly as you ascend into schools of higher grade, but also that its increase is due as well to the poor lighting and seating of schoolrooms. Desks of bad construction and insufficient light both incline the scholar to bring his eyes abnormally near his study in order to increase the size and illumination of the retinal images. And thereby myopia is sadly promoted.

Dr. Carter, of England, pays a handsome compliment to an American authority, which is in point just here.

He says: "Dr. Agnew, of New York, with more practical knowledge and with deeper wisdom, [than many authorities,] pointed out that a feeble and easily extensible character of the ocular tunics would be a condition largely depending upon general debility; and that the treatment of this debility by food, tonics, and exercise, as well as by an ample supply of pure and often renewed air in the school-rooms, a judicious abbreviation of tasks requiring the close application of the eyes, and the use of books printed in bold characters, would be of great assistance in bringing about a much needed reform." After referring sarcastically to the indifference and ignorance on this subject of the average teacher, he cites a very interesting experiment made about 1870, and bearing on the evil of overtaxing the vision of school children while denying them needed physical relaxation. He says: "With reference to the frequent sacrifice of the physical side of the development of the young, it is not uninteresting to recall the results of an experiment made some ten or twelve years ago in the village school at Ruddington, in Nottinghamshire, under the direction of the late Mr. C. Paget, sometime M. P. for Nottingham. In this school Mr. Paget introduced a half-time system as an experiment, to which only a portion of the children were subjected, and which amounted to a substitution of garden work for about one-half of the ordinary school hours. The children who were so treated were found, after a short period, altogether to outstrip in their school work those who devoted, or were supposed to devote, twice as much time to it. The prevention of the increase of short-sight in schools is less, in my judgment, an affair of desks and fittings than of careful and judicious sanitation; for I have no doubt that the optical conditions which would produce myopia in weakly children would fail to do so in robust. None the less, however, should these optical conditions, together with the lighting and distance of the

work, receive a due share of attention; although such mechanical matters must not be expected to supersede the necessity for the constant supervision of a directing intelligence."

In December, 1888, T. F. Bliss, M. D., an oculist of Springfield, Ohio, laid before the Superintendent of Public Instruction the results of his examination of the school children of that city. He kindly sent us his report. His views give such general and emphatic support to those quoted by us from other authorities, that they deserve publication. They are of greater interest to us, being the result of a thorough-going examination in our own country. Our analysis of the author's facts varies from his own somewhat in form, though not in substance.

The pupils examined by him were distributed through all the school grades, and aggregated 3,707. Some defect of vision or disease of the eye was found to trouble about 10 per cent. of them. We have heretofore noticed that investigations in Germany showed 10 per cent. of myopes alone. The myopic tendencies of civilization there seem to exceed those of other countries. But there and everywhere the rule obtains that the higher the school grade the greater the percentage of myopic eyes.

In the five primary grades of the Springfield schools the hypermetropia found amounted to 4 per cent. But no uniform increase of it was manifest in passing upward from one grade to another. The highest reached, 5 per cent., was found in the second grade, and in the very next grade it dropped to 3 per cent., the other grades, first, fourth and fifth, falling between these figures without regard to any law of uniformity. The average of all was between 4 and 5 per cent. In the four grammar school grades the same lack of uniform variation was apparent. Although the highest per cent., 7, was found in the fourth grade, and the lowest, 3 per cent., in the first grade, even the second grade reached 6 per cent., while the third

grade fell to 4 per cent. The average of all, 5 per cent., showed no marked variation from that of the primaries. Hypermetropia in the High school amounted to 6 per cent., being equal to the second grammar, and less than the fourth grammar grade. These facts fail to establish any noticeable development or law of increase in hypermetropia. They point rather to its congenital origin. Observations upon astigmatism indicated a slight tendency upward, but hardly regular enough to develop a law of uniformity.

In myopia the school course appeared to be a marked developing cause, producing a uniformly greater number of myopes in each succeeding higher grade of school. In the lowest primary grade no myopes were found. In the other primary grades the average was 2½ per cent. There was, with a single exception, a uniform increase from the lowest grade to the highest, extending from 1¾ per cent. to 3 per cent. In the grammar grades the average was 4½ per cent., and, with a single exception, there was a gradual increase upward through the grades from 3 per cent. to 6 per cent. In the High school the per cent. was 5. But the number examined, only 105, was smaller than in any other, and considerably so as compared with some grades, several of which numbered five and six hundred. With a wider induction it is not unlikely the figure would have equalled if not exceeded 6 per cent., approximating more closely the results obtained in Germany. Moreover, it is to be remembered that there is a constant tendency reducing this High school figure, in the fact that those afflicted with defective vision are for that very reason more and more led to drop out of school as they advance to higher classes, where the tax upon their eye-sight becomes increasingly exacting. The retention in the higher grades of this ametropic class to the same extent as emmetropes, would materially heighten this percentage we believe. The very facts we

are seeking involve a sifting process whose outcome accomplishes the partial defeat of our search.

The developing law and cause of myopia become still more striking, perhaps, when we remember that it is the least frequent of the three defects mentioned. A contrary supposition as to its frequency is not unnatural in view of its being more noticeable than the other defects. Whether the relative proportion of defects, as classified by Dr. Bliss, corresponds in detail with investigations elsewhere, or not, they do show such a general agreement, we believe, as to indicate that myopia is less frequent, certainly than hypermetropia, and probably than astigmatism. Out of the 3,707 pupils he found about 5 per cent. of hypermetropic, 3 per cent. of astigmatic, and 2 per cent. of myopic eyes.

That 10 per cent. of all children examined had some defect of sight looks like an alarming condition, and one requiring careful attention, the Doctor well says, (though he adds, what may console Springfield in part, though it should arouse school and parental authorities at large,) that in some other cities the conditions are even worse, as we have shown them to be on the continent of Europe. The examination of 1,264 pupils in the Cincinnati schools, by Dr. Williams & Ayers, showed 13 per cent. in the primary and 22 per cent. in the High school, of myopes alone.

In a New York college, 1,620 students gave a range upward throughout the different grades of from 23 to 50 per cent. of myopia.

Tabulating the three defects in the Springfield schools, and giving the results by grades, shows 9 per cent. in the primaries, 13 in the grammar, and 16 per cent. in the High school — an increase of 7 per cent. during the entire school course of nine years. This increase is but a little in excess of that shown in myopia alone, which confirms our

previous statement that the chief development of defective vision due to civilization occurs in myopia.

*Diagnosing Myopia.*— So marked are certain peculiarities of myopia, especially in its higher degrees, that they readily arrest attention. Though less frequent than most other defects, its easier recognition has made myopia comparatively familiar. Its features, in several aspects, are the converse of those exhibited by the hypermetrope. Instead of a dishing facial contour, there is liable to be a fullness of face and eye. On account of this contrast between the two defects, what we said in this connection under the diagnosis of hypermetropia may suffice to suggest what might be said conversely of a myopic eye. The latter is apt, through intra-ocular pressure, to be hard to the touch, comparatively large, prominent and pointed in front. In its higher degrees varied painful symptoms are frequent, and even in lower degrees inflammation and other abnormal conditions may appear. But incapacity to see at a distance is its one uniform symptom. To use the language of Dr. Bliss, reporting his observations upon over three thousand school children: "In most cases of hyperopia and astigmatism, there was a complaint of weak eyes or painful vision, and inability to use the eyes at night for close work; while myopics, unless of high grade, made little complaint except of inability to see at a distance or on the blackboard."

Having made these observations one should next test the eye with concave lenses, and at first, at a distance. If these lenses improve vision the presence of myopia is probable. The paragraph following will explain the need of care at this point, and the necessity, in some cases at least, of administering a mydriatic. After the ciliary muscle is thus paralyzed there is no difficulty in determining by the aid of concave lenses whether the myopia is real or apparent.

*Apparent Myopia.*—Abnormal length of eyeball and excessive refractive power in the media are the two causes of real myopia. Attention is now called to a third cause, through which there is such a simulation of the real as to justify the name, *apparent myopia.* The ciliary muscle in its normal activity increases the crystalline's refraction just enough to meet the demands of near vision. But this muscle may come into an abnormal state of excessive activity. What is called a spasm of accommodation will result—that is, a spasmodic over-refraction of the lens, giving the appearance of short-sightedness; indeed, there is the fact of short-sightedness, though the trouble is not of the nature of myopia. This involuntary accommodative energy may affect emmetropes, and even hypermetropes, to such an extent as to require the reading brought abnormally near the face. The trouble is not in the construction of the globe of the eye or its media, but in the abnormal condition of the ciliary muscle, and the consequent over-refraction of the crystalline. The correction consists in reducing this excessive muscular action. That the trouble lies in the muscle is disclosed as soon as it is paralyzed with a mydriatic. The cause of the spasm is not, as might be imagined, its extra energy, but rather its nervous weakness. This is manifest in the very fact that eyes weakened by over-work are the very ones subject to it. Their asthenopia causes their spasmodic action. This action, it is claimed, may result in developing real myopia out of apparent. Excessive convexity of the crystalline caused by the spasm may involve an intra-ocular pressure, such as convergence does, which will produce posterior staphyloma, a bulging out of the fundus, elongating the eyeball.

Cataract, likewise, is liable to be taken for myopia. Its opacity so reduces visual acuteness that objects are

brought nearer the eye for the sake of larger images and their greater illumination.

*Preventing Myopia.*—In treating presbyopia, hypermetropia, and astigmatism, the important thing is to fit them. Myopia requires to be fitted, also, but needs, in addition, and in an especial sense, a second form of treatment. It should be treated with concave lenses, of course, so far as possible. But its nature is to grow, particularly under favorable conditions, and so the second method of treatment is to check its progress by removing the conditions of growth. Hygienic rules adapted to this end are helpful, not alone to myopia but also to defects of vision of all varieties. The value of this hygienic method is seen as soon as we consider that bad conditions may not only promote the rapid progress of incipient myopia, but may also develop a myope out of an emmetrope, and even out of a hypermetrope.

This developing process is possible because the ocular tissues and tunics in their soft, undeveloped condition in childhood and youth, readily yield to pressure which elongates the form of the eye. All conditions promoting this pressure are to be avoided, and with special care in early life.

What are these conditions? Without discussing them at length, we present the following summary of things to be shunned. All parents, guardians, teachers and specialists charged with the responsibility of caring for and advising the young should note the observations mentioned. Many of these suggestions will be found valuable to all ametropes, and for that matter to emmetropes as well, if they would preserve their vision unimpaired.

Have the eyes examined in childhood, especially before entrance upon school or any other duties that will tax them; if found defective have them carefully fitted.

Remember that physical debility is speedily felt in the eyes, and that the best of ocular treatment cannot fully restore them without needed rest and recuperation. Avoid holding reading or other objects inspected too close to the eyes. Associated with this evil, especially among school children, is the disposition to incline the head forward and downward over the book and desk. Thereby an excess of blood is thrown into the head and the myopic tendency promoted. Choose sunlight as far as practicable in preference to artificial light, and let it fall over the left shoulder, particularly when writing, in order to avoid the shadow of the hand and arm. Exercise care in graduating the intensity of the illumination. In the absence of a standard of light intensity, which the future, we trust, will see established, each must use his best judgment. Electric is the best of all artificial light, and in the incandescent form gives a steady, unflickering flame. Suitable illumination lessens the tendency to improper bodily postures, and the resulting danger of bringing the work too near the face. Reasons like these imperatively call for seats and desks of proper construction in height and other respects, to accommodate scholars of every grade. The teacher can then insist on an erect position of the body, with feet thrown forward under the desk, instead of backward under the seat. With desks suitable in height and properly inclined, the observance of these rules will be compatible with comfort and convenience in study. That textbooks should have type that is clear and of good size is so evident as to hardly call for mention. A final observation is, likewise, so obvious that one wonders at the need of making it. And yet people do need to be told that unless they give their eyes needed rest they must expect to suffer. A wood-chopper expects that when night comes his arms will be too tired to work longer, after eight or ten hours' toil, and so

he makes his plans to give them rest; while the student too often begins to tax his eyes as soon as he is out of bed in the morning, and continues to do so at night, as long as he can hold them open, and much of the time with a poor light, and then he wonders that they become enfeebled after working from fourteen to twenty hours. The wonder is that they hold out as well as they do. The appropriate advice in many a case is, "Give your eyes a rest." Even the heart, contrary to a common supposition, takes, in the intervals elapsing between its beats, one-third of the time to rest.

*Fitting Myopic Eyes.*— 1. Needed observations and information concerning the history and character of the patient should be gathered in diagnosing the case.

2. See that your apparatus for fitting is in good order and conveniently at hand, that needless delays and nervous anxiety on your own and your patient's part may be avoided.

3. Place your test chart 15, or better still, 20 feet distant from the patient.

4. Have the patient point out the line of smallest type he can see distinctly with the naked eye, testing a single eye at a time, and as a rule the stronger one first. At the same time keep the other eye covered. When necessary, bring the test chart near enough for the patient to distinguish one or more lines of type, and then, as the test proceeds, remove the chart until at the completion of the test it stands at a distance of 15 or 20 feet.

5. Being certain that the eye is myopic, begin with a weak spherical concave lens, say ½ dioptry, 78 in inch system. If it improves vision, try next ¼ dioptry, to see if that does equally well, or better, and then ¾ D., and 1 D., and so on. The weakest lens giving best

distant vision is to be prescribed. Proceed with the other eye in like manner. If the two numbers obtained are the same they will give satisfactory binocular vision for distance. If the number before the weak eye differs from that before the strong eye, put the two numbers in a spectacle or trial frame and experiment long enough to see if they furnish satisfactory binocular vision. In case they fail after proper trial, modify the number before the weak eye until harmonious binocular vision is obtained. The refractive number before it may need to be reduced till brought very near, or made identical with that before the stronger eye. Perseverance in wearing different numbers will often so accustom the eyes to them that after a while not only will no discomfort occur, but the best attainable vision will result. If he needs concave lenses for reading they should, as a matter of course, be proportionately weaker than his distance lenses. On the average the difference in their refraction will be about two dioptries. But no general rule should be depended upon in fitting the eye, whatever its defect. Each eye should be fitted in reference to its own individuality and demerits.

6. A myope's distance glasses will sometimes do for reading. If they do not, he should be fitted with a reading pair also, according to the rule for fitting presbyopia, but using concave lenses. It is better, as a rule, to have a second pair. The weakest lenses enabling him to read at a given distance are the best. When no stronger than 2 D. are required for distance, probably none will be required for reading, we have said. But it may be the case, as happens sometimes, when the myopia is slight, that the loss of accommodation will so overcome the myopic effect that the myope will not only need no glasses for reading, but may even require convex lenses for it.

7. The spasmodic action of the ciliary muscle may prevent its full relaxation at the start. An approximate fit will, in consequence, give most comfort at first, and so is to be temporarily prescribed. When worn for a time the muscle will come into a more normal state and so permit a more accurate fit. One or more repetitions of this process may enable us to reach an exact result without resorting to the use of atropine at the hand of a specialist.

## LESSON IX.

### Astigmatism or Asymmetrical Sight.

*Astigmatism.*—The term astigmatism is formed by combining the privative letter "a" with the word stigma. The "a" having the force of a negative signifies the absence of what we might call stigmatism. Stigma means point. If applied optically it would mean seeing in points. The negative of this, or a-stigmatism, is seeing in lines. Notice how this is. In the process of seeing, each visible point in the object observed is reproduced on the retina in an image. All that the mind actually sees is these retinal image points. When vision is normal there is in the image points, an accurate reproduction of the object points. When vision is astigmatic the object points become, in their reproduction on the retina, extended in the form of lines, involving blurred vision. The refractive media distort each point by making it appear spread out or extended. A series of distorted points adjacent to each other along the same meridian gives a blurred line.

None of the visual errors heretofore treated cause such distortion. Their effects, as we have seen, consist not in distorting the form of each point, and so that of the object, but simply in mislocating it — in locating it in front of the retina or tending to do so behind the retina. And their ordinary cause is in the eyeball being too long or too short, though it is occasionally due to the character of the refracting media. In astigmatism, on the contrary, the cause is found uniformly in the refracting media, and generally in the cornea. Occasionally it occurs in the crystalline lens, or the irregular form imposed upon it by the abnormal action of the ciliary

muscle. These facts explain a distinction sometimes made between *corneal* and *crystalline* astigmatism. Astigmatism, in rare instances, has disappeared as soon as the ciliary muscle was paralyzed. This showed that its cause was not an irregularly formed cornea, but rather the abnormal action of the muscle on the crystalline, whereby the shape of the latter became irregular through abnormal pressure, and so distorted the refraction. In other instances an eye apparently free from astigmatism has, upon the paralysis of the muscle, disclosed astigmatism. A case like this is evidence of two facts. First, that the astigmatism is in the cornea; second, that the muscle had exerted such a counteracting effect upon the crystalline, previous to its paralysis, as to neutralize the astigmatism.

Every radiant point, it will be remembered, projects a diverging cone, which, by the refracting function of the media, is reproduced within the eye in a converged cone, giving, as shown in a former lesson, a double cone with bases together. That is, this is the form of the reproduced cone when the media are symmetrical in shape. Symmetry is said to exist in the cornea when its surface constitutes the segment of a sphere; the same is true of the crystalline. Our knowledge of spherical lenses makes it obvious that each cone will be reproduced in proper conical form where this symmetry exists, and so will project a simple point. On the contrary, when the cornea (or crystalline) differs in the curvature of one of its meridians, as compared with another, presenting asymmetry, the reproduced cone must be correspondingly irregular, and, so, oblong in form. It will, in consequence, produce, not a simple point, but an extended image point or blurred line. It is this difference of curvature or convexity and consequent refraction, of different meridians, which makes an eye cylindrical or astigmatic.

In even the average normal eye there is a slight degree of astigmatism. The curvature of the vertical meridian is apt to exceed, by a small degree, that of the horizontal, the cornea constituting strictly the segment of an ellipsoid rather than a sphere. But this difference ordinarily is too inconsiderable to need or even attract attention.

There are in regular astigmatism, two principal meridians, one of maximum and the other of minimum refraction, whose difference of refraction constitutes the defect. These meridians stand at right angles to each other. If only one of them is of defective refraction and stands at 90°, the normal meridian is at 180°, and *vice versa*. If the defective meridian is at 15° the normal one is 90° distant, or at 105°, and so on. Both meridians may on occasions be defective, and then also the rule is that they will stand at right angles to each other.

Let us now notice that when one meridian is normal and the other defective, the one that appears defective, being blurred, is really normal, and the other one is the real cause of blurred vision. That is to say, the apparent defect or the blurring is at right angles to the meridian that is really defective. Take an eye whose curvature departs from the form of a perfect sphere in the region of 90°, its vertical meridian being at the center of the defect, then the blurred meridian will be at 180°. Suppose the defect in curvature be at 60°, then the blurred axis will be at 150°, or 90° from it, and so on. A little close reflection will help this fact to stand out clear and distinct in one's conception. We will take, to illustrate, an eye that is myopic in its vertical meridian. A ray passing through the eye on this meridian, that is, on a line with the plane bisecting the eye on this meridian, will be over-refracted. Each cone projected by a radiant point has, on every meridian or degree, a pair

of rays opposite each other which constitute opposite edges of their plane. The rays of each pair are converged toward each other. In an eye whose refraction is symmetrical the convergence of each pair is such that all the pairs in each cone coincide in the same point in forming their foci. In the above eye, on the contrary, the pair at 90° converges together before some of the others. If the eye were hypermetropic on the vertical meridian they would converge together after some of the others. In either case the image point, so far as affected by the pair of rays on the vertical meridian, will be distorted or blurred. Every pair of rays situated in the same way, their plane being vertical, will develop similar distortion. Now notice, the principle is that the vertical axis being defective all the rays projected from points along the horizontal meridian will be similarly situated and so blurred, and these blurred points connected along the 180° meridian will make that meridian blurred. For these defective rays are excessive in their refraction vertically, but they stand side by side horizontally, and so the blurred line is horizontal. That is, a defective vertical meridian produces a blurred horizontal one and *vice versa*. Or, as we set out to show, the apparent defect is at right angles to the real defect.

Let us, to illustrate more clearly, if possible, regard the eye's refracting media constituted of the surfaces of two convex cylinders, one of these cylinders having its axis vertical and the other horizontal. Take a sheet of note paper and roll its two edges back till they touch each other and it will represent our idea nearly enough to answer as a crude illustration. Held up horizontally it would represent that cylinder of the eye placed with its axis at 180°. Another sheet like it held up vertically would represent the cylinder placed with its axis at 90°. Now suppose the edges of the sheet, representing the horizontal cylinder of the eye, reach just far enough to

touch the retina, then the horizontal line would be clear and distinct; not, however, as we shall soon see, because of any feature of the cylinder when horizontally considered, but rather when considered vertically. If the note paper cylinder is pressed too hard its edges will tend toward a line beyond the retina; if it is not pressed hard enough these edges will not reach the retina; the paper will bulge out, and this bulging out will be up and down. Evidently, therefore, the defect when the edges of the paper fail to touch the retina is up and down or vertical, but the blurred appearance will be horizontal, as that is the line along which the edges of the paper fail to touch the retina. Manipulating the vertical note paper cylinder similarly, it furnishes the same illustrations, the chief one being as before, that the real defect is at right angles to the apparent defect. Manipulated at any other angle the illustration would be the same.

So much misapprehension has occurred on this point that the reader will indulge us while we vary the form of illustration somewhat and expand a little farther. The refracting media of the eye are the equivalent of a spherical convex lens, and such a lens is equivalent to, for it is made up of, cylindrical convex lenses whose axes cross each other at each and every angle. Now, suppose the vertical meridian whose refraction is determined by the horizontal cylinder to bulge out more, be more convex than the others. Then rays passing through it are refracted too much, the vertical meridian is myopic, and these rays fail to reach the retina, and so leave blurred points associated side by side along a certain line and thus give the effect of a blurred line. The question is, what is the direction of the line. To simplify the illustration, let us think of the media as equivalent to two cylindrical convex lenses at right angles to each other, which is practically true. In the above illustration the vertical meridian is myopic, and the horizontal one is normal, and

we are seeking to find on which meridian the blurred line appears. Suppose we hold the lens that is horizontal between a light and a screen and at the focal distance from the latter. There will be a bright horizontal line. Why? Because the lens refracts perfectly, not on its horizontal meridian, which is plane, and so does not refract at all, but on its vertical meridian, which is at right angles. Hold the other cylindrical convex lens vertically at the focal distance from the screen and there is a vertical bright line. Why? Because the lens refracts perfectly, not on its vertical meridian, which is plane, but on its horizontal, which is at right angles. Thus, the axis of the bright line is at right angles to the axis of perfect refraction. By contrary, the axis of the blurred line is also always at right angles to the axis of imperfect refraction. Combine these cylinders so that they represent an astigmatic eye, and this becomes still clearer, if possible. Combine them so that the vertical axis is myopic and the horizontal is normal. Rays passing through the vertical meridian are refracted too much, and produce in consequence a blurred line, but as this over-refraction is vertical, the over-refracted pairs of rays must stand side by side horizontally, making the blurred line horizontal. The real defect, which is vertical, is at right angles to the apparent defect shown in the blurred horizontal line. On the other hand, the horizontal meridian being normal, that is, situated at the focal distance from the screen, has perfect refraction horizontally, and so shows a clear bright line vertically.

Now the eye, we have said, may be conceived of as composed of numberless surfaces of cylinders, each modifying the form of the others, until the combination constitutes the surface of a sphere. Hence the foregoing illustration may be employed at any axis and the right angular relation of the two principal meridians shown.

Notice, in the next place, that in passing from one

degree to another on the circumference of an astigmatic eye the defect increases or diminishes gradually, not by sharp variations, and especially so in regular astigmatism. Conceiving of the media as constituted of convex cylinders makes this clear. In the above example, therefore, the astigmatism reaches its maximum point at 90°, but shades off gradually in each direction. The pairs of rays at 89° and at 91°, respectively, fall short of the retina, as does the 90° or vertical meridian, but not quite so much as it, and so the meridians each side of 180° are blurred, but not so much as at 180°. Every additional degree that you remove from the vertical axis the rays come nearer to touching the retina and the corresponding right-angled meridians diminish their blurred, indistinct appearance. Upon reaching the meridian at right angles to the one of maximum indistinctness, it will be found of maximum distinctness and clearness. Making the eye artificially astigmatic with either a plus or minus cylinder, and then using the proper neutralizing cylinder to correct it, will furnish illustration and demonstration of the facts above mentioned.

*Regular and Irregular.*—The discussion thus far prepares for an exact classification and definition of astigmatism. Speaking in general terms we have found it due to a difference of refractive power in different meridians. As a description of regular astigmatism, this is correct. But occasionally there will be a difference of refractive power at different points on the same meridian. This is called irregular astigmatism. It is a variety that cannot be fitted correctly since it is impossible to grind a lens to correspond to its irregularity. Some small measure of irregular astigmatism often characterizes the regular. This explains in part the frequent difficulty experienced in fitting astigmatism, and why entirely satisfactory results are not more common. Classifications of regular astigmatism follow.

*Astigmatism, Simple and Compound.*—When an eye that is astigmatic in one meridian has no additional optical trouble its defect is called *simple astigmatism.* If an eye has, in addition to its astigmatism, some other trouble, like presbyopia, hypermetropia, myopia, etc., we call its double defect *compound astigmatism.* If both the principal meridians are astigmatic, as sometimes occurs, there is what may be called *cross astigmatism*, and this also is compound, of course, and is usually mixed astigmatism.

*Hypermetropic Astigmatism.*—If the astigmatic meridian is hypermetropic we have hypermetropic astigmatism, the rays on this meridian tending to a point beyond the retina. And it is simple hypermetropic astigmatism, provided the other meridians are all normal; if they are not, it is compound hypermetropic astigmatism.

*Myopic Astigmatism.*—If the astigmatic meridian is myopic we have myopic astigmatism, the rays on this meridian tending to a point inside the retina. And it is simple myopic astigmatism provided the other meridians are all normal; if they are not, it is compound myopic astigmatism.

*Mixed Astigmatism.*—If there are two astigmatic meridians, opposite in character, one being myopic and the other hypermetropic, we have what is called mixed astigmatism.

Simple hypermetropic astigmatism is fitted with a cylindrical convex lens; and simple myopic astigmatism, with a cylindrical concave. Compound hypermetropic astigmatism is fitted with a cylindrical convex lens combined with a spherical convex lens. A cylindrical concave lens combined with a spherical concave lens is used to fit compound myopic astigmatism. Mixed astigmatism is fitted with a compound lens consisting of

a cylindrical lens, convex on one side and concave on the other, with axes at right angles. This combination constitutes a cross-cylinder. A cross is reducible to a sphero-cylinder of equivalent value, equivalent in practice as well as mathematically.

Inasmuch as an equivalent sphero-cylinder fits an eye that has cross-astigmatism, it is desirable to know how to reduce a cross-cylinder to its equivalent sphero-cylinder. For the sake of simplicity in stating our rules let us regard one member of a cross-cylinder, preferably the weaker, as its first member, and the other as its second. In mixed astigmatism the signs of the two numbers are unlike, being opposites, one plus and the other minus. The rule in this case is as follows: Write the first or weaker member as a spherical lens, retaining its sign. Then write the sum of the two members as a cylinder, giving it the sign and axis of the second member. These two results united by the symbol of combination will give the equivalent sphero-cylindrical lens.

Except in cases of mixed astigmatism there is no propriety whatever in prescribing a cross-cylinder, and so there is really no call for any rule but the one above. But as examiners will sometimes prescribe cross-cylinders where signs are alike, it is well to be prepared to reduce a cross of any form to an equivalent sphero-cylinder. Where the signs of both members are alike the rule is as follows: Write the first or weaker member as a spherical, retaining its sign. Then write the difference between the two members as a cylinder, giving to the result the sign and axis of the second member. United by the symbol of combination these will constitute the equivalent sphero-cylinder. The rules differ only in this, that when the signs are unlike the members are added; when alike, one is subtracted from the other.

The reason for the rule is, that in writing the first member as a spherical, retaining its sign, we have

modified it either positively or negatively, according to whether its sign is plus or minus, to the extent of a cylinder of the refractive number of itself, but with its axis at right angles to it. And consequently the second member must be reduced in the opposite direction to an equal extent, that is by the same cylinder, to maintain the equivalence of value, and the result be written as a cylinder having the axis of the second member. Or, to vary the statement of the principle and process, if the first member is carried to a certain extent at a given axis in the direction of plus, the second member must be carried equally far at the same axis in the direction of minus, in order to maintain the necessary equivalence of refractive value, and *vice versa*.

The following cross-cylinders reduced to equivalent sphero-cylinders will illustrate these rules:

− 1. Dc ax. 180° ⌈ +2. Dc ax. 90° = −1. Ds ⊃ +3 Dc ax. 90°

+½. Dc ax. 60° ⌈ −1. Dc ax. 150° = +½. Ds ⊃ −1½ Dc ax. 150°

+ 1. Dc ax. 170° ⌈ + 2. Dc ax. 80° = + 1. Ds ⊃ + 1. Dc ax. 80°

− 1. Dc ax. 40° ⌈ − 2. Dc ax. 130° = − 1. Ds ⊃ − 1. Dc ax. 130°

While some specialists object to the use of equivalent sphero-cylinders in place of cross-cylinders, others favor it, and so facility in employing these rules in making transpositions is desirable.

As a sphero-cylinder may be expressed in two or more equivalent forms, in some of which the signs of the two members will be unlike, while in others they are alike, it is desirable to attain facility in making these transpositions also.

Some are indifferent as to whether both members of a sphero-cylinder shall be alike or unlike; others regard it better in a refractive sense to have them unlike. To

say the least, it gives them the periscopic form. It also makes the convex lighter, and that must be considered an advantage. When the signs of the two members are alike proceed as follows: Add to the refractive number of the spherical another spherical of the number of the cylindrical, and make the result the number of the spherical in the new, equivalent formula, written as its first member, and with the spherical sign of the old formula retained. Then write the number of the cylindrical in the old formula as the number of the cylindrical in the new, making it the second member of the same, but with its sign changed, and its axis also, so that the axis will stand at right angles to what it did in the old formula.

To illustrate the rule take the folllowing sphero-cylinder. Written with both signs alike its form is as follows:

$$+ 2\tfrac{1}{2} \text{ Ds.} \supset + 1 \text{ Dc. ax. } 90^\circ$$

In transposing it according to the rule the first or spherical member in the equivalent formula becomes + 3½ Ds. By this modification of the spherical the refractive power of the combination has been increased to the extent of 1 convex cylinder at 90° and 1 convex cylinder at 180° (these two being equal to 1 spherical convex), and consequently the combination must be diminished just that much in its second or cylindrical member in order to maintain an equivalence of refractive power. That is, we have, in effect, added to the spherical member 1 plus cylinder at 90° and 1 plus cylinder at 180°, and so we must add to the second or cylindrical member 1 minus cylinder at 90° and 1 minus cylinder at 180°. The minus cylinder at 90° added to the second member will just neutralize the plus cylinder at 90°, which it already contains, and so will reduce to zero. Adding now the minus cylinder at the opposite angle we

have for the second member — 1 D c ax 180°. The equivalent sphero-cylinder is thus found, in conformity with the rule, to be

$$+3\frac{1}{2}\text{ Ds} \bigcirc -1\text{ D c ax. } 180^\circ$$

Some may prefer to explain the above process in language slightly different, though identical in meaning, as follows: In adding 1 D spherical convex to the spherical, we add to it, at 90°, the power of the cylinder in the second member; and so the spherical contains, at 90°, just what we want, and hence the cylinder disappears; but at 180° we have added 1 D too much. Therefore we must take away 1 D at 180 degrees.

Having worn both forms, one having like signs and the other unlike, the writer is not prepared to pronounce in favor of either, believing them to be practical as well as mathematical equivalents.

To transpose a formula where the signs are unlike to an equivalent one having signs that are alike, it is obvious that the process must be reversed, and subtraction be employed in the place of addition, the cylinder being taken from the spherical. Difficulty will occur only when the cylinder is larger than the spherical. It will, in such a case, be impossible to express an equivalent sphero-cylinder with like signs; but a sphero-cylinder with unlike signs and of different form and equivalent value can be expressed. In such a case the rule is to subtract the spherical from the cylinder, and write the result as the spherical of the new, equivalent formula. Then, for the second or cylindrical member of the new formula, write the cylinder of the old formula with its sign changed and its axis placed at right angles to what it was in the old formula.

For the benefit of some who may better understand the making of the transpositions if stated somewhat

differently, we now vary the form of our explanations, rules and illustrations. Before doing so let us make sure that we appreciate the principle governing all transpositions, viz.: That *both members are to be modified equally, and that this can be done by uniting to each member the same factor with opposite signs.* If the uniting factor have the plus sign when it is united to the first member, it must have the minus sign when united to the second member, and *vice versa.* In other respects the factor must remain unchanged. The one service to be rendered by the rules now to be given, is to tell what the uniting factor must be in each kind of transposition.

Let it be remembered that there are three kinds of transposition: 1. From a cross cylinder to a sphero-cylinder. 2. From a sphero-cylinder to a cross cylinder. 3. From a sphero-cylinder of one form to one of another form. We are now prepared for the rules showing, respectively, what uniting factor to use in each of these three kinds of transposition:

RULE I.— *To transpose a cross to a sphero-cylinder, the uniting factor may be the numeral of either member with the axis of the other member, and with its own sign when united to itself, and with the opposite sign when united to the other member.* It is better, as a rule, to take the smaller numeral as the uniting factor. The following examples will illustrate the rule:

$$\begin{array}{ll} +\tfrac{1}{2}\text{ Dc ax. }110^\circ & \overline{\text{—}}\ 1\text{ Dc ax. }20^\circ \\ +\tfrac{1}{2}\text{ Dc ax. }20^\circ & -\tfrac{1}{2}\text{ Dc ax. }20^\circ \\ \hline \multicolumn{2}{c}{+\tfrac{1}{2}\text{ Ds} \supset -1\tfrac{1}{2}\text{ Dc ax. }20^\circ} \end{array}$$

$$\begin{array}{ll} +2.5\text{ Dc ax. }90^\circ & \overline{+}\ 1.5\text{ Dc ax. }180^\circ \\ -1.5\text{ Dc ax. }90^\circ & +1.5\text{ Dc ax. }90^\circ \\ \hline \multicolumn{2}{l}{+1.\text{ Dc ax. }90^\circ \supset +1.5\text{ Ds.}} \end{array}$$

For the uniting factor in the first formula, we take the numeral in the first member, ½ Dc, with the axis of the other member, 20°, and when uniting it to itself retain its own sign, and when uniting it to the other member change the sign. Uniting it to the first member we have two plus cylinders of the same power combined at right angles to each other, and that equals one spherical of the same power and sign, viz., + ½ Ds. Uniting it to the second member with the sign changed, according to the rule, and we have, as the signs are alike, a quantity obtained by simple addition, viz., —1½ Dc ax. 20°. These two results united by the sign of combination constitute a sphero-cylindrical lens equivalent to the cross cylinder. In the second formula we have used the second member as the uniting factor, viz., 1. 5 Dc ax. 90°, with its own sign, +, when united to itself, and with the opposite sign, —, when united to the first member. Thus we see that the second member of a cross may be used for the uniting factor as well as the first. Doing this causes the spherical in the result to stand as the second member and the cylindrical as the the first. It seems to us better, however, to make a practice of writing a sphero-cylinder so that the spherical member shall stand first. But this is optional, and for the sake of the illustration we have in the second example so written the quantities that the order is reversed.

*RULE II.—*To transpose a sphero-cylinder to a cross (which is the converse of the previous process) the uniting factor consists of the spherical number written as a cylinder*

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*NOTE.—In the EYE-ECHO for July-August, 1890, we published the substance of these three rules with illustrative examples. The transposition from a sphero-cylinder back to a cross was taught, not by addition, as is done here, but by subtraction, according to the algebraic principles for the same. Hence the signs of the uniting factor as then given were necessarily the reverse of what they are here.

*having the axis of the cylindrical number, and also, when united to the spherical member having its sign unlike the sign of that member, but having the opposite sign when united to the cylindrical member.*

$$\begin{array}{rl} + \tfrac{1}{2}\text{ Ds} \supset - 1\tfrac{1}{2}\text{ Dc ax. } 20^\circ & \\ - \tfrac{1}{2}\text{ Dc ax. } 20^\circ & + \tfrac{1}{2}\text{ Dc ax. } 20^\circ \\ \hline + \tfrac{1}{2}\text{ Dc ax. } 110^\circ & - 1\text{ Dc ax. } 20^\circ \end{array}$$

The spherical in the first member, + ½ Ds, may be resolved into the two plane cylinders, + ½ Dc ax. 20°, and + ½ Dc ax. 110°. If we unite to these the uniting factor, — ½ Dc ax. 20°, this factor and the cylinder, + ½ Dc ax 20°, cancel, and + ½ Dc ax. 110° is the remainder, as shown in the first member of the result. Uniting the factor to the second member of the sphero-cylinder we have the second member of the original cross cylinder. These two results, united by the sign of combination, give us the original cross cylindrical formula. Similarly, the second sphero-cylinder may be reduced back to its equivalent cross.

*RULE III.—*To transpose a sphero-cylinder from one form to another, take for the uniting factor the numeral in the cylindrical member written as a spherical, retaining its sign when it is united to the spherical member, but changing its sign when it is united to the cylindrical member.*

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*NOTE.—Rules I and III are of frequent practical use; rule II, hardly ever.

To illustrate, take the following examples:

$$\begin{array}{lcl} -4\text{ Ds} & \supset & +3\text{ Dc ax. } 90^\circ \\ +3\text{ Ds} & & -3\text{ Ds} \\ \hline -1\text{ Ds} & \supset & -3\text{ Dc ax. } 180^\circ \end{array}$$

$$\begin{array}{lcl} -2\text{ Ds} & \supset & +3\text{ Dc ax. } 90^\circ \\ +3\text{ Ds} & & -3\text{ Ds} \\ \hline +1\text{ Ds} & \supset & -3\text{ Dc ax. } 180^\circ \end{array}$$

The refraction of each member of the original formula in each of these last examples consists of a stronger power than is necessary. The improvement made in this respect by the transposition is manifest. The two formulas above transposed have unlike signs. The result of the first transposition, it will be noticed, gives an equivalent with like signs. By reducing it back to its original form, it may be seen that the rule applies equally, whether the signs of the two members are alike or unlike. In some cases, as in the following, the sphero-cylinder reduces to an equivalent plane cylinder, the first or spherical number reducing to 0. We write the cypher as the first member of the result and follow it with the sign of combination ($\supset$), simply for the sake of illustration, but in the ordinary writing of a plane-cylinder these ought, of course, to be omitted.

$$\begin{array}{lcl} -1.\text{ Ds} & \supset & +1.\text{ Dc ax. } 90^\circ \\ +1.\text{ Ds} & & -1.\text{ Ds} \\ \hline 0 & \supset & -1.\text{ Dc ax } 180^\circ \end{array}$$

*Diagnosing Astigmatism.*— Glance at the face and head. If they are irregular in conformation that fact will prepare you to watch more expectantly for astigmatism, as well as for other errors of refraction, as explained heretofore. From the prevalence of hypermetropia, astigmatism is oftener found associated with it than with other defects, and this makes hypermetropic astigmatism a common variety.

Astigmatism being congenital in origin those suffering from it are likely to complain of having had poor vision since childhood. In school they were troubled, perhaps, with a blurred, confused sensation, or a running together of the letters in reading, teachers, in their ignorance, chiding them unjustly, and they, not knowing the cause of their trouble, being too much dazed and disarmed to make defense. But in case the defect has been slight, and the exactions on vision not severe, they may have lived to advanced years and hardly realized their inferior visual power. Tipping the head and looking sidewise across the bridge of the nose may suggest the presence of astigmatism. Diminished circles of diffusion and other possible benefits may be derived from these movements. Noting and passing incidental indications like these direct the patient's attention to an astigmatic test chart located 20 feet distant, and on which dark radiating lines are displayed at various angles. If there is to the patient a marked difference between the lines, some appearing clear and dark, and others looking lighter and blurred, this indicates the presence of astigmatism. Astigmatic letters may also be used, made of parallel lines standing in each letter at a different angle. A difference in the look of the letters suggests the presence of astigmatism.

If the patient is so myopic or hypermetropic that vision is too dim to make the test conclusive, he should step nearer the chart, or it should be brought nearer him,

till he can see whether or not there is a difference in the appearance of the lines.

Or the operator may fit his hypermetropia or myopia, whichever it is, as nearly as possible, and then the radiating lines will doubtless become sufficiently distinct for the patient to pronounce, at 20 feet distant, whether some of the lines are blacker and others are lighter and blurred. If fitting with spherical lenses clears up the blurred look it proves that the trouble was myopic or hypermetropic, and not astigmatic, and that spherical lenses will suffice. If, on the contrary, the blurred look continues on some meridians and a blacker look on others, it is evidence of astigmatism.

Having diagnosed the case, as above, we now suggest the following steps. Our procedure will involve the diagnosis as well as fitting of the special variety of astigmatism present. Carrying the two processes along together will involve a partial repetition of what has been written upon diagnosing, but there will be no objection to the learner, in this, if he is helped to master the fitting of this most difficult of refractive errors.

*Fitting Astigmatism.*—1. Notice if with the naked eye some of the radiating lines are blurred and others at right angles to them are blacker and clearer.

2. If so, try successively spherical convex and spherical concave lenses to see if the blurred look can be removed; but if, on the contrary, vision becomes poorer, or, at least, no better, it is pretty conclusive that you have a case of simple astigmatism. Caution must be exercised at this point. Spherical lenses will probably be found that will correct the refraction so as to improve vision on the blurred meridian, but if they damage it as much on the meridian at right angles, where the clear black lines first appeared, it shows that a spherical lens is probably not needed, but that a plane cylinder is.

3. Now proceed to fit the patient with a cylindrical convex or a cylindrical concave lens, as may be required. In doing so, place the axis of the plane cylinder at right angles to the blackest line, which will bring it on a line parallel with the blurred lines. Begin with a weak lens and proceed to stronger numbers substantially as when fitting with sphericals. If the patient is properly fitted with a cylindrical convex lens, it is a case of simple hypermetropic astigmatism. If he require a cylindrical concave lens, it is a case of simple myopic astigmatism. When the correct lens has been selected the blurred look will disappear, all the lines will look equally clear, distinct and dark.

4. Caution. But suppose your astigmatic patient has hypermetropia, or myopia, as shown in the diagnosis. Then fit him with the proper spherical lens, and while it is before the eye add the proper cylinder, according to the rule just given for fitting simple astigmatism. The spherical first selected to correct the hypermetropia or myopia may need to be modified, perhaps reduced or increased in strength, to get the best correction, after the cylinder has been added. And possibly a farther modification of the cylinder may then be made to advantage. In a word, special care is to be taken to secure the best possible combination of spherical and cylindrical lenses to fit the given case.

If the eye can be properly corrected according to this last rule, you have a case of compound hypermetropic or myopic astigmatism. If there is error or insufficiency in the muscles of rotation, a prism-cylinder may be required, or possibly a sphero-prism-cylinder.

5. In compound astigmatism some operators prefer to fit the astigmatism first. Beginning with cylinders, they first correct the asymmetry of the eye according to the rule for correcting simple astigmatism, setting the axis over the blurred lines at right angles to the darkest,

clearest line. The power of the lens is modified until the lines, placed where they can be easily observed, are all seen to look alike. That cylinder is the proper one which balances the refraction of the two principal meridians. Then, whatever hypermetropia or myopia is present is to be corrected with the proper spherical lens while the cylinder is before the eye.

6. The dealer may occasionally meet a case of mixed astigmatism which can as well or better be tested with cross-cylinders. First, fit the meridian of greatest ametropia as nearly as may be, and then, while this cylinder is before the eye, fit the other astigmatic meridian with another cylinder. Modify each cylinder in turn till the best result is reached, the same as the two lenses are modified alternately in fitting other cases of compound astigmatism. When the proper cross-cylindrical combination is thus obtained it will be found, as previously explained, that an equivalent sphero-cylindrical lens will answer equally well.

*Supplementary Suggestions.*— It would be pleasant to indulge the thought that we have written enough, and have done it with sufficient plainness to make the subject of astigmatism clear to an optical tyro. But knowing by experience that an abstruse question may defy repeated efforts to render it clear, and may, at last, disclose its character only when one has persisted in changing his standpoint until he has reached a view-point which to him is higher and better than any before attained, we venture to submit a few additional suggestions.

It is of interest to note that the refractive error in simple astigmatism, the existence of which appears in the blurred lines alone, can be measured and so tested even with spherical lenses, although it cannot be fitted with them. Suppose the refractive error causing the blurred lines is hypermetropic, then a spherical convex lens of

the proper correcting power will cause their blurred look to disappear and so will show the power of the convex cylinder needed to fit the given eye. While the proper spherical lens will remove the blurred look from the blurred lines it will at the same time develop them at the opposite angle, that is, at right angles to the angle first blurred. Obviously, therefore, the spherical lens is unsuited to fit an eye having simple astigmatism although capable of indicating what cylindrical lens will do so. Suppose the refractive error causing the blurred lines is myopic, then a spherical concave lens will develop a similar set of facts and show the concave cylinder required. With a stenopaic slit before the eye, the slit on the angle of blurred vision. the above method is sometimes quite satisfactory. Nevertheless, although the character and refraction of the cylinder needed to correct simple astigmatism is discoverable with spherical lenses alone, it is obvious that the most satisfactory way is to make the test as well as the fit with cylinders. When the right cylinder is found and set at the proper angle it will secure the best vision possible to the given eye. Observing the above directions carefully the operator should readily find the proper plane cylindrical lens to fit any given case of simple astigmatism.

In this connection a better understanding may be obtained, perhaps, of the meaning of what has been said about there being two principal meridians standing at right angles and the refraction from one to the other varying gradually. If so, one will thereby gain in the correctness of his conception of the character of astigmatism. If, by any means, one may obtain a clearer conception of astigmatism, it may be worth the while for us to amplify to the point of tediousness, and for the student reader to pore over the lesson until the subject lie in the mind as clear as a snowflake under the microscope.

It is not accidental, but is necessitated by the nature of the case, that the principal meridians, with rarest exception, stand 90° apart. Also, of necessity, one is the meridian of maximum and the other of minimum refraction. If the blurred lines are cleared up with a concave lens they are caused by the meridian of maximum refraction which stands at right angles to the blurred lines. If they are cleared up with a convex lens they are caused by the meridian of minimum refraction which stands at right angles to them.

In the first case, the meridian is too convex, and as you pass from it toward the other the convexity gradually diminishes until you reach the meridian of minimum convexity. In the second case, the meridian of minimum refraction is not convex enough, and as you pass from it toward the other the convexity gradually increases until you reach the meridian of maximum refraction. If the meridian of maximum refraction is abnormal and that of minimum refraction is normal, it is a case of simple myopic astigmatism. If the meridian of minimum refraction is abnormal and that of maximum refraction is normal, it is a case of simple hypermetropic astigmatism. If both meridians are too convex, one, however, being more so than the other, it is a case of compound myopic astigmatism; the meridian of maximum and of minimum refraction being both corrected by concave lenses,—one by a spherical and the other by a cylindrical concave. If both meridians are deficient in convexity, one, however, being more so than the other, it is a case of compound hypermetropic astigmatism, the meridian of maximum and that of minimum refraction being both corrected by convex lenses,—one a spherical and the other a cylindrical convex. If both meridians are abnormal, but in an opposite sense, one being too convex and the other not convex enough, it is a case of mixed astigmatism, the meridian of maximum

refraction being myopic, and that of minimum refraction hypermetropic. A cylindrical concave lens will correct the former meridian, and a cylindrical convex, the latter, constituting in combination a cross-cylinder whose equivalent sphero-cylinder will also fit the same eye.

## LESSON X.

### Strabismus or Cross-Eye.

*Nature of Strabismus.*—The word strabismus means to turn aside. The direction of the eye, and so of its axis, is controlled by the muscles of rotation, as explained in Lesson I. They exert their energy largely in pairs, each rotary movement depending upon the associate work of one or other of the three pairs into which the six muscles are divided. None of them act singly, except the internal and external recti. As might be expected, the two muscles associated are often of the same class, and yet they are frequently of different classes. The superior and inferior recti are associated when the cornea is to be elevated or depressed in conjunction with a slight inward movement. On the contrary, the association is between the superior rectus and the inferior oblique, instead of inferior rectus, when looking directly up; and when looking directly down it is between the superior oblique and inferior rectus rather than inferior oblique. In each muscular rotation, it is to be observed, even where a single muscle is employed, the other muscles contract more or less.

The function of the internal and external recti is to rotate the eye inwardly and outwardly around a vertical axis. They likewise enable the two eyes to be so converged that the vision of both can be fixed upon the same point, the exertion devolving upon the internal recti. Thereby we obtain what is called binocular vision, that is, single vision with two eyes. It is necessary to this that corresponding muscles in the two eyes act with corresponding vigor. When they fail to do so the visual

axes of the two eyes are directed toward different points, and harmony of vision is destroyed. This is known as strabismus or cross-eye.

*Classes of Strabismus.*—The direction of the deviating eye or eyes gives a classification of strabismus which we will mention first. When the vergence is inward it is called *convergent strabismus*; when outward, *divergent strabismus*. Rarely it will be up or down. In the last two instances it is often due to paralysis. Oculists, in whose charge it should be placed, most certainly if serious, designate it when up, *sursumvergens;* when down, *deorsumvergens*.

Another classification distinguishes between strabismus as *paralytic* and *non-paralytic*. It may be, when inward or outward, as well as when up or down, the consequence of paralysis, though not frequently. The non-paralytic class is usually known as *concomitant*. Where there is no mal-adjusted muscular relation between the two eyes their axes stand parallel when looking into distance and when they converge, as is necessary in near work, the convergence between them is correspondent and equal. So in their divergence, when they look to the right or the left there is equilibrium of action and of direction between the two eyes. In concomitant strabismus this equilibrium is destroyed. Both eyes move together, however, covering an equal range of vision as to their accommodation, convergence and divergence. In this consists their concomitancy, or mutual accompanying of each other in their movements. But the range of vision while equal is never identical or correspondent, nor is the direction of their visual axes identical or correspondent. In all these particulars, while the eyes move together, they are not mates in the sense they are when there is muscular equilibrium. When in equilibrium, the visual axes naturally focus or fix upon the same point in looking

near by or at a distance, whereas, in strabismus, they fix upon different points.

When the squint is in one eye only it is called *unilateral strabismus*; when the squint is first in one eye and then in the other, either eye being able to fix, it is said to be *alternating strabismus.* Sometimes the squint occurs irregularly, or at intervals; it is then named *periodic strabismus.* When the condition remains permanently the same it is called *constant strabismus.*

An additional distinction is made between *real* and *apparent* strabismus. In Lesson V brief reference was made to what is known as the angle *a*, or *alpha*, as it is sometimes called. The form of the eyeball is oblong. A line through its longest diameter intersects it centrally from front to fundus, passing through the center of its refracting media from cornea to crystalline. Such a line is known as the eye's *optic axis.* It gives the angular direction toward which the eye points — toward which it will appear to look. The direction of the eye's vision, the visual axis — the direction toward which it really looks — does not coincide, or rarely does so, with the optic axis. The posterior pole of the visual axis strikes the center of the *macula lutea.* The posterior pole of the optic axis is inside the macula in emmetropia, and in hypermetropia still further inside, while in myopia the distance it strikes inside is less than in either of the others, and in high degrees of myopia this distance may be reduced to zero, the two axes coinciding; or, the myopia may be so great as to cause the posterior pole of the optic axis to be even outside the visual axis.

Now in hypermetropia the posterior pole of the optic axis may lie so far inside that of the visual axis that the outward pointing of the eye may give the appearance of *divergent* strabismus, notwithstanding the visual axes of the two eyes may be normal in their mutual relations to each other. In high degrees of myopia the optic axis

may point so far in as to give the appearance of *convergent* strabismus, and yet the visual axes may be perfectly normal. These misleading appearances are what constitute that which is known as *apparent strabismus*.

When it comes to strabismus, the greatest specialist in our country, without doubt, is George T. Stevens, M. D., Ph. D., of New York. Any one desiring to give special attention to this branch of ocular optics will do well to read his work on Functional Nervous Diseases. For the benefit of those who may not have his writings at hand, but who wish to know in a general way the most advanced views on the subject, we make liberal extracts and citations showing his theories, methods and classifications.

Strabismal affections have uniformly been discussed under the head of insufficiencies of the ocular muscles. He regards the term as misleading and inadequate. The philological and physiological precision of terms adopted by him renders their currency so probable that we gladly give his classification.

Where the action of the muscles of rotation is normal he describes the condition by the term *orthophoria*, derived from two Greek words whose combined meaning is *tending right*. When there is a mal-adjustment of the visual axes, due to lack of equilibrium in the rotary muscles, he indicates it by the general term *heterophoria*, tending differently, that is, different from the direction in which the eyes tend in *orthophoria*. He makes the following sub-classes under *heterophoria*:

1. "*Esophoria*, a tending of the visual lines inward.

2. *Exophoria*, a tending of the lines outward.

3. *Hyperphoria* (right or left), a tending of the right or left visual line in a direction above its fellow."

This last term," he explains, "does not imply that the eye to which it is referred is too high, but that it is higher than the other without indicating which one is at fault."

The question occurs why Dr. Stevens did not carry his classification a little farther. It would certainly seem that the distinguishing term ought, where possible, to indicate which is the faulty eye, and also designate its fault. The classification fails a little at this point. For example, we may say right *hyperphoria*, and yet not indicate whether the fault is in the right eye in a deviating tendency abnormally upward, or in the left in a deviating tendency abnormally downward. To avoid confusion in what follows, remember that the faulty location of the image is in the opposite direction of the abnormal deviation or vergence of the eye. Suppose we had a term for abnormal tendency downward, involving, should the fault become established, faulty location of image upward. Then the fault described could be attached to the faulty eye. The Greek prefix *hyper* means *over*, while the prefix in Greek for *under* is *hypo*. Why not use the one, where appropriate, as well as the other? The only objection is their similarity in spelling and sound. But we need no more confound the two than we do "emmetropia" and "ametropia." We could then speak of right *hyperphoria* with certainty that it meant abnormal tendency of the right eye upward, and of left *hypophoria*, that it meant abnormal tendency of the left eye downward. Let us improve our enunciation and we shall have less fear of words similar in sound. It would be well for English-speaking people to remember that there are languages where the same word, with a half-dozen or more variations of mere accent or inflection, will give as many various meanings.

Perhaps it is the very excellence of Dr. Stevens' classification that tempts one to inquire as to a possible improvement such as just suggested. There is no other,

certainly, that compares with his in exactness and detail. He uses compound terms to indicate tendencies in oblique directions, as *hyperesophoria*, where the tendency is upward and inward; or, *hyperexophoria*, a tendency upward and outward.

It must not be overlooked that these terms are not intended by Dr. Stevens as classifications of actual strabismus, but only of tendencies toward it. His use of them is not so much where strabismus is manifest as where it is latent. He says, "Hyperphoria is that condition in which, with the ability to maintain binocular vision, there is a tendency of one visual line in a direction above the other. Strabismus, in which there is an actual turning of the axis of one eye above the other, differs from hyperphoria in the absence of ability to maintain single vision." That actual deviations of the eye upward and downward were long ago pointed out and operative measures taken for their correction, he freely admits. His claim to originality at this point he bases on his having first called special attention to hyperphoria, the deviating tendencies upward and, by contrast, downward, as a frequent anomaly of the ocular muscles.

His chief merit as an operator and investigator he considers, as we understand, to rest primarily on his developing the doctrine of latent tendencies in the muscles toward strabismus and the evils consequent upon them, which tendencies he names in the classification above cited.

*Causes of Strabismus.*—The immediate cause of strabismus, as indicated in its definition and classification, is an abnormal inequality of vigor between different muscels of rotation. Behind this immediate cause is a primary one consisting of some form of ametropia, which subjects one or more muscles to abnormal strain. These, with other causes, lead to muscular weakness, and sometimes paralysis. The weakened muscle or muscles, unable to respond to the will, fail to secure proper convergence.

The most frequent primary cause of convergent strabismus is hypermetropia. With the excessive demand upon accommodation there is an accompanying and equally excessive demand for convergence, their action being associative and reciprocal. This involves excessive strain upon the external recti, under which they are liable to become weakened and so unable to prevent the eye turning in abnormally in its effort to maintain a ratio of convergence corresponding to the degree of abnormal accommodation required in the hypermetropic eye. So marked is the reciprocal effect upon each other of convergence and accommodation, that an increase of the accommodative energy will increase the convergence effort were there nothing else to do it. Where the hypermetropia is in only one eye, or is worse in one eye than in the other, the poorer eye suffers most from abnormal convergence strain, and is the more likely to be affected with squint. In the midst of variations of theory the above line of explanation seems the most reasonable and finds most general support. It is no longer to be doubted that *strabismus convergens* has its origin, as a rule, in hypermetropia.

The most frequent primary cause of divergent strabismus is myopia. The explanation of this can be given in fewer words, now that we have seen the reason for convergent strabismus. The nearer the eye the reading is held, the greater the convergence effort required. The excessive refraction in myopia makes this nearness and the consequent convergence excessive. Moreover, the elliptical form of the myopic eye increases the difficulty of its convergence beyond that of the hypermetropic eye, which is more spherical, and so more mobile. With increased need, and yet with diminished capacity to converge, excessive strain must fall upon the myopic eye. Upon what point does it fall? Upon the internal recti, because convergence is executed through

them. Becoming wearied and weakened, one of them gives out, if not both, convergent control of the eye is lost, and *strabismus divergens* results.

Exceptions to the above laws occur. Occasionally myopes, and even emmetropes, have convergent strabismus; and, on the other hand, hypermetropes, and also emmetropes, may have divergent strabismus.

*Diplopia.*—The function of the eye being that of a camera, there is projected upon the retina of each eye an image of the object looked at. In normal vision this image is formed on parts of the retina that exactly correspond in the two eyes. With proper convergence there results a blending into one, or fusing of the two images, giving binocular vision. In the absence of proper convergence this fusing of the images cannot occur; but the two images may be seen as separate and distinct. This is apt to be the case in the incipiency of the trouble. If not a continuous experience (and it rarely or never is), the patient may, especially when throwing his eyes in some particular direction, be led to exclaim, "I see double," two objects instead of one appearing in the field of vision. After a time, however, he is likely to ignore one of the images, the one in the weaker, more afflicted eye. There comes to be an involuntary suppression of one of the images, leaving the individual practically dependent on monocular vision. Though disuse will cause the visual power of the cross eye to deteriorate steadily, it is likely to retain a measure of its acuteness for a good while. This may be shown by covering the healthy eye, as the cross eye may then be found able to fix the object in vision, and a sufficiently discernable image of it rest upon the retina to secure vision.

Diplopia is apt to persist in paralytic strabismus as it does not in concomitant where the weaker image, as explained, is likely in time to be suppressed. Diplopia is always in the opposite direction to the deviation.

*Evil Effects of Strabismus.*—The least of the evils of cross-eye is the disfiguring of the countenance by facial contortions and the blemishing of the most powerful, expressive and impressive feature of the face. All this is surely bad enough, but it is trifling as compared with other consequences.

* To avoid repetition the reader is referred to Lesson VII, pages 105 to 107, for a brief general discussion of effects of hypermetropia similar to those mentioned in this paragraph. Results there referred to as consequences of hypermetropia are to be considered as consequent also upon strabismal conditions, and, as Dr. Stevens, who leads us all on this question, may seem to imply, to a greater degree in the latter than in the former, though he lays great stress upon both, including strain on any and all ocular muscles. The excessive innervation which depletes and debilitates the nervous system in both latent and manifest hypermetropia will, as already discussed, serve as an illustration of the depletion resulting from excessive innervation to any of the muscles of rotation. The reader will be glad in the absence of details to get the general scope of this question. We can give this in no better way, perhaps, than to begin by quoting the fundamental proposition laid down by Dr. Stevens: "Difficulties attending the function of accommodating and adjusting the eyes in the act of

* Note.—It is but fair to say that when the passage in Lesson VII was first prepared the author had given but cursory attention to Dr. Stevens' work, and was not awaie that his theory of neuropathic causes embraced in so equal measure excessive strain of the ciliary as well as rotary muscles, as the citations following show that it does.

vision, or irritations arising from the nerves involved in these processes are among the most prolific sources of nervous disturbances, and more frequently than any other conditions constitute a neuropathic [nerve-suffering] tendency."

It is instructive to notice the reasoning by which he leads up to the generalization contained in the above proposition. Nerve difficulties he regards as due to predisposing causes and immediate causes. The former are neuropathic tendencies; the latter consist of evil conditions in one's environment, like vitiated atmosphere, or imperfect illumination, or conditions in one's system of a pathologic nature, like a fit of sickness or mental excitement. The immediate causes are transitory and far less serious as evil influences than the predisposing tendencies. These latter may be hereditary, yet they may transmit each a form of nervous disorder different from itself. They constitute a class of causes to which little or no attention has heretofore been given, but because of their significance and serious effects deserve careful consideration. The permanent tendency may not be intense enough to originate the nervous affection, but when it is originated by temporary disease that tendency may be strong enough to perpetuate it. "It may, for instance, be of little practical importance that a child first manifested symptoms of chorea [St. Vitus' dance] while under the influence of fright. The evil has been accomplished, and the event cannot be recalled, nor can such an influence be regarded as permanent or of long continuance. Hence, if the child continues to manifest symptoms of chorea, it is reasonable to search for an underlying cause which is permanent or continuous. *Otherwise it would be necessary to assume that, as a result of the immediate cause, some radical disarrangement of nervous action originated which perpetuates itself.*" The italicising of the last sentence is ours. It is deserved.

The reasoning is cogent, the phraseology is striking and suggestive, and the whole passage wonderfully illustrative of the position maintained. He supports his position by saying that "Such radical disarrangement has not been demonstrated, nor is its existence at all probable. The hypothesis, therefore, that there is an underlying cause of disturbance, becomes stronger in proportion as the idea of a radical disarrangement is surrendered. Such underlying causes are fully recognized by students of nervous disorders, and their existence is so constantly verified by the daily experience of medical observers that their importance cannot be questioned."

The next step in his argument is that this predisposing cause need not be general, "pervading the whole organism, thus affecting the whole nervous system," but it may "be entirely local affecting directly only a limited number of nerves. An irritation set up in any nerve gives rise to the greatest variety of disturbances in any or all other parts of the organism, however distant. Hence it is not logically necessary to suppose a universally pervading or even a centrally initial irritation in order to explain the neuropathic predisposition." This doctrine, he claims, has been proved by the experiments of Sir Charles Bell, Marshall Hall and Dr. Brown-Séquard.

Finally he raises the inquiry whether these local irritations may not consist of "some peculiarity of anatomical structure, or of physiological adaptations, which is inconsistent with the most regular and easy performance of the function of a part or parts." He answers this inquiry in the affirmative, basing his answer upon the examination of "twenty-six hundred and ninety-two cases of nervous diseases in private practice and of a considerable number of cases in public institutions." His answer he generalizes in the proposition quoted to the effect that irritations to the nerves resulting from excessive effort and strain imposed upon the muscles of

accommodation and rotation "are among the most prolific sources of nervous disturbances."

If these things are so, opticians ought to realize it. Otherwise they are unprepared even to give intelligent advice in many cases, to say nothing about correcting defects of vision which have caused reactions involving nervous disorders, by which corrections they might have been able to remove the disorders.

It is not as though Dr. Stevens stood alone. Many other specialists stand by and support his views. It is not as though it were simply a plausible theory. Numerous cases are given in illustration and confirmation. The theory affirms that where ametropia exists there is excessive strain, and particularly so in harmonizing the accommodation and convergence, and this causes perplexity and confusion. Also where there is lack of correspondence between the rotary muscles, an incoordination in their associate reciprocal activities, excessive strain and perplexity result. These may follow whether the cause is latent or manifest. This strain and the perplexity consequent upon it, (the latter, Dr. Stevens thinks, more, perhaps, than the former,) may result in reflex neuropathic disturbances or nervous disorders, depleting nervous energy to the point of culminating in the prostration of the system, and even in paralysis.

However reasonable his theory may seem, he does not ask that it be accepted as of practical value unless it can be "shown that practical results may be deduced from its application." Consistent with this statement, he "attempts to show that such results may follow with a surprising uniformity." He cites cases under his own treatment "illustrating, first, the effect of correcting each of the more commonly recognized defects of refraction and association; second, by considering at greater length several of the more familiar conditions of nervous disturbance; and, third, by attempting to show the results

of such connections in a given number of consecutive nervous disorders of serious nature."

The reader desiring to investigate this subject more thoroughly should not fail to read Dr. Stevens' work. To show how matter-of-fact his illustrations are, and how vividly and explicitly they set forth and support the the theory held, we will quote a few cases whose narration is given with brevity.

"A lady, aged twenty-one, had suffered so greatly from facial neuralgia during many years that, among other radical measures for relief, she had submitted, by medical advice, to the extraction of all her teeth, notwithstanding they were all sound. She was found to have astigmatism, and strong cylindrical glasses were prescribed. The neuralgic paroxysms ceased within a few days, and have not returned during eight years."

The following cases we take the liberty to condense: "A lad, aged seven; pain in and above the eyes; very nervous—suffered two years from chorea. He was weak—disinclined to amusements of childhood, and often ill in various ways. His trouble proved to be a high degree of hyperopia. He was fitted with appropriate glasses, which greatly pleased him. Recovery from his nervous troubles followed. The change was rapid and remarkable. The lad continued to gain strength and was within a few weeks in all respects in better health than he had ever been before. Ten years had passed up to the citing of the case, but no return of the nervous trouble."

"Annie W——, aged ten, had always been subject to severe headaches located in temples and back of head. She was rarely free from suffering. Pains increased when she attempted to look at books. She was pale and thin, walked with feeble step, and seemed quite exhausted with very moderate exercise. Her facial muscles were so inactive that there was little expression in her countenance. Her speech wholly lacked vivacity, and in all

respects, she seemed to be in a state of great nervous exhaustion. There was found in this case marked insufficiency of the external recti muscles, and very slight adductive power when accommodation was relaxed. After increasing the adducting power by exercise, partial tenotomy of the internal rectus was performed under the influence of chloroform. The child commenced very soon to gain strength and elasticity; expression came to the face and vigor to the limbs; the headaches ceased, and mental energy followed. She has continued well during the three years, and is now advanced in her studies beyond most of her companions of the same age."

"Mrs. M—— had sick headaches fifteen years; attacks about once a week. Eyes treated two weeks. Reported a year and a quarter afterwards in perfect health. Had had no attack since ocular treatment. No such respite had been known in fifteen years."

"Miss Alice ——, tall, of fine form, but thin and extremely pale. Lips colorless; conjuctiva pearly white. For nine years has had migraine or sick headache once or twice a week. Pain always unilateral, attacking one or the other eye and supraorbital region and extending downward along the course of the branches of the fifth nerve. With each attack she was forced to bed; intense nausea and vomiting always present. Compound myopic astigmatism was found with insufficency of the internal recti muscles. Correction with lenses and by tenotomy of muscles resulted in a perfect cure. Her health improved from the time of the operation, the color returned to her face, she gained in weight and strength, and, although a year has passed she has not had an attack of migraine."

But, you say, are not these exceptional cases? The Doctor's answer is a decided negative. At the date of writing he had treated twelve hundred and eighty patients for chronic headache. He takes seventy-three

typical cases to show the proportion of cures effected—cases which he had an opportunity to follow up so as to make a satisfactory record of results. His record reads:

| | Per Cent. |
|---|---|
| Permanently relieved, . . . . . . | 83.6 |
| Improved, . . . . . . . . . | 12.4 |
| Not cured, . . . . . . . . . . | 4. |
| | 100 |

In the same way he takes eighty-five cases of neuralgia, and his record is:

| | Per Cent. |
|---|---|
| Permanently relieved, . . . . . . | 83.53 |
| Materially Improved, . . . . . . | 11.76 |
| Not relieved, . . . . . . . . | 4.71 |
| | 100 |

*Similar examples are cited and arguments adduced to show that in like manner the correction of abnormal action in the ocular muscles is sufficient in a large proportion of cases to cure spinal irritation and neurasthenia, chorea, vertigo, insomnia, hallucinations, epilepsy, migraine or sick-headache, stomach troubles and resulting brain and bowel difficulties, and various other physical maladies, especially when of a nervous complexion. His emphasis of mental disorders leaves us to see that oculists and opticians may enter the very precincts of the insane asylum and prove themselves among the greatest of benefactors.

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*Because of personal and family experience and observation, we have catalogued some troubles to which Dr. S. makes but incidental reference, as though of equal importance with others to which he gives extended emphasis.

*Diagnosis.*—Enough has been said, perhaps, to indicate how to distinguish between paralytic and concomitant strabismus. In the former, the characteristic is non-concomitancy of movement between the eyes. If, for instance, the rotary muscles of one eye are normal and those of the other are paralyzed, the paralytic eye will not accompany the normal one fully throughout the entire circle of its rotation. It may, and will if paralyzed only in part, follow it somewhat, but to an extent less than that included by the range of vision covered by the normal eye. The more you approach the direction calling for excercise of the paralyzed muscle, the less will that eye act concomitantly with the other. There is a relation of dissociation between the two eyes in all forms of strabismus, but the characteristic by which a paralytic form may be recognized is, that this relation is not uniform but variable. When looking at a distance in some one direction their visual axes may be parallel or nearly so, while the angular difference between them in looking in other directions will constantly vary from a minimum to a maximum limit.

By contrast the concomitant variety is easily distinguished. Not only are the visual axes of the two eyes not parallel when looking in the distance, and not only do they fail to converge equally when looking at an object near by, the two axes being displaced or out of harmony in their relation to each other, but — and this is their distinguishing feature — these visual axes, though displaced, accompany each other, reciprocally moving over equal angular distances, notwithstanding the arcs of these angles are not identical. The angular difference of direction between the two axes remains the same, whatever the rotation of the eyes.

Another way to aid in distinguishing between these two varieties is to remember that diplopia is more apt to characterize the paralytic form, especially when looking

in some certain direction. In concomitant strabismus the false image is likely to be suppressed as it is not in paralytic. The explanation of this, as given by Longmore, is that in concomitant strabismus, while the true image always falls on the macula, the false image always falls one side of the macula, on the same spot. The portion of the retina on which the latter falls not being equally acute with the macula, and not being the proper place for it, this false image is vague and dim, and continues to grow more so because the retina at that point is not equal to the demands upon it for nervous energy, and becoming exhausted in consequence, suppression of the image follows, then disuse and amblyopia. In paralytic strabismus the false image varies its location to such an extent that exhaustion of the retina and consequent loss of the retinal sensibility does not result, and the "strabismal subject finds himself unable to suppress perception of the second image when it ever occurs."

A difference of view obtains on this theory. It is questioned by some whether amblyopia ever results from strabismus.

The following method will readily enable one to recognize each kind of strabismus. Direct the patient to fix upon an object fifteen or twenty inches distant. It will be the normal eye that will fix. Now cover that eye with a frosted lens, or even your hand held so that you can watch the movement of the covered eye. Then, again, direct the patient to look at the same object. The diseased eye will now fix, or attempt to fix, upon the object, and at the same time the well eye will shift or rotate in the same direction that the poor eye does. If the rotation of the two eyes is equal, the strabismus is concomitant; if the rotation of the well eye is greater than that of the other, the strabismus is paralytic.

Suppose the strabismus is only apparent, what test will discover the fact? Cover each eye in turn and

neither will be found, when covered, to deviate. Why? Because each is already fixed upon the same point before either is covered.

Suppose the strabismus so slight that the operator is uncertain which one it is that deviates. Then have the patient fix upon an object held at the point of the distance test, and while he does so, watch his eyes as you gradually bring the object nearer to him. The normal eye will steadily converge upon the object until the near point is reached, while the affected eye will not. At some point, while approximating the object, an inward or outward deviation of the latter eye will commence.

*Treatment of Strabismus.*—With the surgical or pathologic treatment of strabismus we have little to do. Well qualified oculists should be consulted when resort to such treatment is desired. The surgeon's knife is often used, especially in early life, with signal benefit. Albeit, the optician ought, for the sake of the treatment he may afford or the counsel he may offer, to have a fair understanding of the trouble. On this account, and because greatly increased attention has been called to strabismus of late, we have discussed it more at length than would otherwise have been done. The instructions we offer bear upon the optical treatment of strabismus.

In diagnosing latent strabismus, prisms are needed, and so its diagnosis and treatment will be carried along together.

1. Knowing which is the deviating eye, and observing the degree of its deviation, determine by trial, beginning with a weak prism, what power is best adapted to harmonize the action of the two eyes, and so secure satisfactory binocular vision. The base of the prism requires to be placed over the weakened muscle, its apex being in the direction of the eye's vergence.

2. Often it is best to divide the prism, placing one over each eye, especially if the prism is quite strong. A 4° prism, base in, would be of the same effect as two 2° prisms, one over each eye, bases in. If the 4° stood base out, both of the others would need to stand likewise. If the 4° stood base down, one 2° would also need to stand base down, and the other would have to stand base up. The one prism would throw the deviation two degrees up in one eye, while the other prism would throw the deviation in the other eye two degrees down, and thus secure binocular vision by bringing the visual axes both on the same horizontal line. A 5° prism might be divided into one 3° and another 2° prism.

3. If the strabismus is latent, determine what the strabismus tendency is. (In the latent there may be greater innervation and so greater loss of nervous energy than in the manifest.) An approved method is to use a light as the object to be observed upon a dark background, at a distance of twenty feet. With a prism of sufficient strength, base in, and placed before either eye, diplopia will be produced, two images appearing, the one on the right being seen by the right eye, and the one on the left by the left eye. If both images are in the same horizontal plane, no strabismal tendency is manifest. If one image, for example, the one before the right eye, drops below the other, the tendency in the visual axis of that eye is upward or above its fellow. If the fault is in the right eye, it is in an inferior muscle or opposite to the deviation, and so the prism base should be placed over that muscle, hence base down. If the fault is in the left eye, it is in a superior muscle, and so the base should be up, if the prism is placed over that eye.

Similarly create diplopia vertically with a prism of sufficient strength, base down. If both images are in the same vertical plane, no lateral strabismal tendency is manifest. If they are not in the same plane, one image

being to the right of the other, there is a lateral tendency inward or outward. Applying the principles above, set the base of the correcting prism in or out, as required to place it over the weakened muscle so that its apex shall be in the direction it is necessary to throw the image to secure binocular vision. Divide the prism as before, when desirable.

4. What if the total latent tendency to strabismus does not manifest itself? Proceed on the same principle as in latent hypermetropia. Fit with a prism that corrects what is manifest, and after wearing, additional degrees of the latent will be apt to become manifest, and can then be fitted.

5. What if none can be made manifest by the above method? Perhaps there will be none needing correction. If there is reason to believe that there is, then subject the muscles to a series of exercises involving abduction, adduction, sursumduction, and deorsumduction, as noted below under prism and orthoptic training. In this way any relative weakness in one or more of the rotary muscles may be discovered and corrected.

6. *Caution.* Always at the start prescribe a prism fully as weak or, preferably, weaker than the degree suspected necessary. Otherwise you may develop an abnormal strabismal tendency. It is easy, after additional latent tendency becomes transformed into the manifest, to increase the power of the prism correspondingly.

7. All ametropia should usually be corrected before these tests are made. Dr. Stevens says this precaution is not essential, as a general thing, in testing for hyperphoria.

8. Prism and orthoptic training of the rotary muscles is practiced, by which it is sought to measure their relative strength and strengthen weak muscles by subjecting them to a few minutes' exercise each day in overcoming

the power of prisms. The adducting and abducting power of the lateral muscles is thus tested and trained, and also through sursumduction and deorsumduction similar efforts are expended upon the inferior and superior muscles. A chief difficulty in strabismus is the inharmony between the accommodation and convergence.[1] To correct and regulate this a stereoscope is used to advantage, in which the images of two objects are sought to be fused in one. The patient may find difficulty in doing this at a distance with the objects far enough apart to be respectively on parallel lines separated the width of the eyes. If so, they are brought close enough together to make this possible. Then the objects are gradually separated, and then approximated toward the eyes, and vision trained to harmonize convergence and accommodation, till the proper fusion of images involved in binocular sight is secured. Some recommend putting a bandage over the normal eye, and having corrected the ametropia of the weak eye, train it in monocular vision. In this way it is sought, especially, to develop lost retinal sensibility and perception. The method does not find universal approval among oculists. But all are agreed that after what is possible has been done to correct strabismus, by correcting its ametropia, by fitting with prisms, and by the best possible training, resort should generally be had, if farther correction is necessary, to tenotomy, the surgical treatment of the muscles of rotation. Indeed, some are so confident in the last method, and have such limited faith in others, at least when unassisted by the surgeon's knife, that they recommend tenotomy as the first resort. Judiciously used, each method has doubtless served its purpose in the detection or correction of muscular insufficiencies.

## LESSON XI.

### Asthenopia or Weak Sight.—Anisometropia or Unequal Sight.—Amblyopia or Retinal Dim Sight.—Nephelopia or Medial Dim Sight.

### Asthenopia.

The formation of this term from Greek words indicates its meaning, weakness of eye or weak sight. It is often induced by weakness of the muscles of rotation, and so is a common accompaniment of strabismus. It is then known as *muscular asthenopia*. The word muscular applied to the eye may mean the ciliary as well as the rotary muscles. Hence, we prefer the expression rotary or motor asthenopia. At other times it is due to excessive exertion or a weakened condition of the ciliary muscle, in consequence of ametropia, when it is naturally called *accommodative asthenopia*.

Though both the above causes may be absent, there being no ametropic condition or muscular defect present, still, similar ocular weakness may be manifest in consequence of the debility of the physical organization, especially the nervous system, or the excessive exercise of vision. *Sympathetic* or *reflex asthenopia* is a proper designation.

*Causes of Asthenopia.*—Weak sight sustains a general relation to the other defects of vision similar to that which physical debility sustains to the various bodily diseases. Diseases are causes; debility is a result of any one or

more of them. Ocular defects are causes; asthenopia is a consequence of any one or more of them. Each kind of asthenopia can be traced back with average precision to its particular cause. The exceptions to this rule only establish it.

Accommodative asthenopia is usually accompanied by hypermetropia as its cause. It is but natural that it should be, as the over-strain in hypermetropia is upon the muscle of accommodation. As a matter of course, hypermetropic astigmatism and convergent strabismus may also act as causes of accommodative asthenopia. Asthenopia is also a natural consequence of uncorrected presbyopia.

In myopia the accommodation required is less, instead of greater, than normal, and so there is no strain of the accommodative muscle. The strain is in rotating the eye convergently. Hence, myopia is apt to be associated with motor asthenopia as its cause. Then, again, myopic astigmatism or divergent strabismus, or both, are found in association as causes.

The term employed to characterize reflex asthenopia, together with the definition given above, indicates its cause. After protracted illness, and during poor health, more or less sympathetic asthenopia is sure to be present. The sensitive character of the eye makes it the first of the physical organs to suffer from and report any general debility. During convalescence the temptation to over-tax the eyes in reading is very great. At such a time, though the eye be perfect as to its emmetropic and muscular character, it will quickly suffer from over-exertion, and reflex asthenopia will be induced.

*Remedies for Asthenopia.*—The principal treatment suitable to each kind of asthenopia suggests itself at once. The first thing needed is to remove the cause so far as

possible, by correcting all presbyopic, ametropic and muscular defects, and, also, all errors of habit and evil hygienic conditions. This being done, the asthenopia may be expected to disappear, at least in large measure. The over-taxing of the eye, however, while working under the disadvantage of its mal-formation or mal-adjustment, will often reduce its vigor and vitality to such an extent that it can never recuperate entirely.

One who has been so unfortunate as to break his arm will hardly be surprised to be told by the surgeon that no form of treatment can fully restore its original strength. But much can be done for the arm and for the eye by proper skill, by needed rest for recuperation, and by the exercise of care to avoid over-taxing them. If means like these fail to accomplish for the eye all that seems attainable, the patient should employ hygienic and other constitutional treatment to tone up his debilitated physical system.

If glasses for reading are already worn there may seem to be need of strengthening their refraction. Circumstances must guide as to this. If the immediate use of the eye is imperative and exacting, an increase of strength may be advisable, at least till the restoration of health justifies a discontinuance of the added refractive power. When no malformation exists, and though the patient be too young for presbyopia to have set in, a weak glass for reading and near work may be temporarily helpful. If symptoms of sympathetic asthenopia appear in patients of this class, a spherical convex lens of one-half or even one-quarter dioptry may be found to give much relief, especially in work by artificial light. "Rest-glasses" is a not innappropriate descriptive term which we have heard used. When the cause of the asthenopia is removed, the discontinuance of glasses will naturally follow, in case no other ocular deficiency has appeared.

## Anisometropia or Unequal Sight.

The two eyes are said to be isometropic when they are of equal refractive power; when their refraction differs they are called anisometropic. One eye may be emmetropic and the other ametropic, or, one more hypermetropic, or more myopic, or more astigmatic, than the other, or one hypermetropic and the other myopic; or any compound combinations of these, involving unequal refraction. The defect may be acquired or congenital.

The evil results usually accompanying the respective faults of the two eyes may naturally be expected. The consequence most common, perhaps, is asthenopia. The inharmony between the convergence and accommodation accounts for this. Through the non-concurrent action of convergence and accommodation, the latter may have to make an effort to fix for fifteen inches, and yet that distance on the part of accommodation may call for a corresponding effort on the part of convergence which would naturally fix at ten inches. This conflict between the two, and struggle by each, can but result in enfeebling the ocular muscles.

*Treatment of Anisometropia.* — The general rule already given for fitting eyes of unequal refraction is to fit each separately when this gives comfortable binocular vision, and when it does not, to fit the better or more used eye, upon which there will be chief dependence, and then vary the refraction of the lens before the other eye just enough to secure satisfactory binocular vision.

It is sometimes said that no general rule is serviceable in fitting the eye,— that each case must be a law unto itself. Though a measure of truth attaches to the proposition, it is certainly a mistake to say that the exceptions are more numerous than the rule. Certain common principles and modes of procedure do guide the operator in

fitting a majority of cases. But this "law-unto-itself" principle, it must be admitted, is especially applicable in fitting anisometropia. This is especially true where the refraction of the two eyes is of opposite character, one being positive and the other negative. Experiment alone will determine whether each eye can be fitted independently and the two work in harmony, and, if not, whether the greater modification must be made with the convex or with the concave lens. A modification of each may prove practicable, not only where the lenses are opposite but where they are of the same class. The difference between the eyes is occasionally such that one eye is adapted and employed for distant and the other for near vision. Any attempt to harmonize such eyes in binocular vision is likely to be equally needless and futile. The safest course is to experiment with different combinations until the best attainable has been found, the character and comfort of the wearer and the distance at which his work is held, all being taken into consideration.

Before concluding, however, it ought to be said that the consideration of agreeableness to the patient, or comfort, must be held in abeyance in some cases, if the best permanent results are to be attained. The correctness of the test may be too probable for question and yet the patient may complain of discomfort. He is often to be encouraged to persist in wearing the lenses selected, at least, at intervals, with the expectation that after sufficient use they will become entirely comfortable. The ground for this advice may be explained to him through some simple illustration like the following: A child left uninstructed is apt to cramp his fingers improperly in writing. Comparative ease and facility in penmanship may be attained in spite of it. When the teacher corrects the false position, and thus the abnormal contraction of the finger muscles, there may be complaint of discomfort and strain in the new but proper position.

Still he will rightly urge his pupil to persist, assuring him that in the end his comfort and facility as a penman will not only be equal but greater than before. If the patient cannot be made to see with the lenses prescribed, as well as he would like, he should be made to consider, if it is true, that after a time the muscles of the eye will become accustomed to their changed positions the same as the finger muscles, and then satisfactory results will be altogether probable. One other thing ought to be said. While the optician should relax no effort to reach the best result attainable, he and his patient should both understand that a perfect fit is at times impossible, and the operator who always guarantees one is a self-confessed fraud.

## Amblyopia.

We use this term in its broadest sense to include all forms of impaired vision resulting from defects in the retina involving mal-acuteness. Most retinal affections dull its perceptive powers, and to that extent render dim the images focused upon it. Two general causes may be mentioned, the poisoning of the retina and its atrophy, or wasting away from lack of nourishment. In addition to vitiating diseases and habits that communicate poisoned conditions, Mittendorf mentions such poisons as the following, whose effects upon the retina are often especially deleterious: liquor, lead, tobacco and quinine. Only an oculist can decide what constitutional treatment is needed. Lenses are not correctives. Possible help may come occasionally and temporarily, to some extent, by using a cataract lens to increase the illumination.

Try the eye through a pin hole disc. If, with the peripheral rays thus shut off, vision on the test chart is not improved, it is pretty good evidence of retinal impairment.

## Nephelopia.

Impaired vision has thus far been shown to be caused by:

1. Malformations of the eyeball and media.

2. Mal-adjustments and strain of ocular muscles.

3. Mal-conditions in the retina. And now we come to cause number

4. Consisting of mal-conditions or opacities in the refracting media, designated *nephelopia*, meaning, as its derivation shows, cloudy vision. As in amblyopia, the thing for the optician to do is to learn to detect the general nature of the cause sufficiently to refer it to the oculist for treatment. Any one of the numerous diseases from which each of the refractive media may suffer, may leave a scar or obstruction interfering with the passage of light. Changes resulting from morbid conditions in the appendages of the eye as well as in its media, or resulting from old age, may develop in the cornea, crystalline or humors, a cloudy, hazy state. Disease may contract the pupil and shut out light. Simple observation will often suffice to disclose the defect. A bright light thrown upon the eye, laterally, may assist. An ophthalmoscope will often be of great service.

*Aphakia.*—The removal of the crystalline lens, as in cases of cataract, sometimes becomes necessary. The Greek term *phakos* means lens, and so Donders adopted the word *a-phakia*, meaning absence of lens, to describe the condition. The crystalline has a refractive power of between ten and eleven dioptries. Its absence must leave the eye very hypermetropic except where it was previously very myopic. A previous myopia equal to the

refraction of the crystalline, would, of course, when removed, leave the eye emmetropic. The excessive hypermetropia usually resulting from aphakia can be relieved by fitting with a cataract lens. There will be no range of accommodation as that has been destroyed. Different pairs of lenses will be needed for different visual distances. The crystalline lens may be dislocated by a jar or other injury, resulting in the aphakic condition, and sometimes in diplopic vision. In addition to removal of the lens by extraction, or its change of place in the eye by luxation, aphakia may result from a puncture of the lens which will cause it to dissolve.

## LESSON XII.

### COLOR-BLINDNESS.

*Invisible Spectrum Colors.*—There are colors, or more properly, rays, *beyond* both edges of the spectrum, known as ultra red and ultra violet, invisible to the human eye. There are persons to whose eyes colors *within* the spectrum are invisible. It seems at first thought a strange anomaly. But what if a correct theory of light and color should find it no more difficult to explain the invisibility of spectral colors than of ultra rays? In the absence of a settled view on the subject we hazard the suggestion as a provocative of thought. Were the various theories of light under discussion, it would be natural to inquire how our usually accepted hypothesis for the explanation of light accounts for these invisible ultra rays, if at all. It is a burden laid upon every hypothesis that it should harmonize with, if not elucidate fully, all facts involved in the subject for the explanation of which it is summoned.

*What is Color-Blindness?*—To prepare for this inquiry, let us recall the character of the solar spectrum. We find that through Newton and his successors the world has learned that light is a compound which we can decompose and show to consist of seven colors, each one of which is simple, as is shown by the fact that when passed through a second prism it cannot be farther decomposed. Now the character of an eye that is normal as to its color sense is that it can distinguish between these colors and even note various tints and blendings of them. Quite a difference may exist among such eyes, however, as to the acuteness of their color sense. Some

will be enabled, through practice, to make nicer distinctions than others, though the radical colors will always be distinguished if the color sense is normal. It is remarkable how color perception may be developed through training, the same as the ear may be educated to note distinctions in sound which were utterly undiscernible before ear culture. So the taste may be trained till the tea-taster will detect any special brand of tea or any mixture of brands.

Unlike the eyes just described, that have normal color sense, the eye that is color-blind cannot distinguish all the spectral colors. It may distinguish some of them, but others it will confound. Green and red are the most often confounded. Red cherries, for example, can be distinguished from the leaves of the tree only by the difference in their shape. *Achromatopsy* is the word employed to express total inability to distinguish any one or more of the colors. Any partial inability or dullness of color perception is termed *dischromatopsy*. There have been persons who were unable to make any distinctions whatever between colors, but such cases have been extremely rare. Their only way of making distinctions was by noting differences in depth of tint or shading, colors seeming to them simply more or less intense. The ordinary manifestation of achromatopsy is a blindness for red or for green, or for both.

The order in which these forms of color-blindness are named indicates their relative frequency. Blindness for blue or violet is rare. Color-blindness is apt to affect both eyes alike, but exceptions have been known where it existed in one eye alone. The defect is sometimes congenital. In other cases the color perception is normal at birth, but is subsequently damaged or destroyed by some diseased condition of the optic nerve or retina. The subjects of color-blindness, like myopes and hypermetropes, are liable to remain ignorant of their color-blind

condition, supposing that others distinguish between colors the same as they do themselves, simply by differences in their intensities. Over four per cent. of men are subject to color-blindness, while less than one per cent. of women are said to be. This disparity in favor of woman may be accounted for, by her greater practice in comparing colored goods and matching colors. Color-blindness does not seem to constitute a predisposition toward any other ocular defect. Its subjects are no more liable to ametropia than others. The reader will find the word Daltonism sometimes used to designate color-blindness. The origin of the term is in the fact that the defect was first described by Professor Dalton, who was color-blind himself. Sir David Brewster, on this account, attached the Professor's name to the trouble.

*Causes of Color-blindness.*— In considering the causes of color-blindness we enter a *terra incognita*. The opinions of authors are characterized to a large extent by expressions of uncertainty, or at the most of mere probability. Still, the various opinions offered by them may prove none the less interesting. Speaking of one of the promoting causes of color-blindness, Dr. Wolfe makes some statements at once amusing and striking. "It is most probably caused," he declares, "by the intermarriage of cousins or other near relations. Hence, very likely, why Quakers furnish a large contingent of color-blind. Dr. Wilson records six males in one family — uncles, nephews and cousins — who were all markedly color-blind, which defect has descended to them from their maternal uncle. They all belonged to the Society of Friends. One of them, a minister of that body, bought for his wife a bottle-green dress, and for himself a coat of bright scarlet, instead of the conventional drab."

But what is the physiological cause of color-blindness, the reader will naturally ask. On this point a late writer,

Sir T. Longmore, affirms that "the abnormal anatomical conditions on which color-blindness depends have not yet been demonstrated, and even the true nature of color sensation is as yet undetermined." For a brief statement of the view most commonly quoted by authors touching the function of the retina in discriminating and, likewise, in failing to discriminate color, we think Mittendorf's most succinct and clear. "The layer of rods and cones of the retina is called the perceptive layer, and is supposed to be especially concerned in the act of vision. The rods are supposed to be for the quantitative, and the cones for the qualitative perception of light. We know that the eyes of night-birds, like owls, that have no occasion to distinguish between colors, have no cones whatever; their retina being made up of rods entirely, is best adapted for the quantitative perception of light." The macula lutea which is made up entirely of cones, is not only the seat of the most acute vision, but also of the most vivid perception of colors. This is taken to lend support to the theory that the cones discriminate light qualitatively, that is, as to color. Going toward the periphery the perception of color as well as of form diminishes. Hence his definition of color-blindness: "A lack of faculty for the discrimination of colors which appears to be due to an imperfect development or impairment of certain nerve elements of the retina, *probably due to a want or deficiency of the cones.*"

Despite all uncertainty respecting details it is not unnatural to suppose there must be some differences between the nerve elements of the retina or between the functional powers of these elements, corresponding to their differences in the recognition of different colors. Brewster advocated Newton's view that the fundamental colors are red, yellow, and blue. On that theory there are three kinds of nerve elements involved in color perception. One kind recognizes red, another yellow, and

the third blue. This theory makes green and violet compound or mixed colors. The theory advocated by Helmholtz and Young varies from the above chiefly in the fact that it differs as to what the fundamental colors are. Its claim is that they consist of red, green, and violet or blue. In expounding the theory, Longmore says, "If the elementary fibres which are concerned in the perception of these three fundamental colors are equally excited together in normal eyes, the resulting impression is that of white; while the impression of compound or intermediary colors depends on the fact of either two, or of all three, of the retinal color elements being severally excited in greater or less proportion among themselves. The cause of defective, or of completely deficient perception of color, depends upon a faulty or undeveloped condition, or upon a total absence of one or more of these retinal color elements. Although the hypothesis just named is the one which is very generally accepted instead of the Newtonian view of the three primary colors being red, yellow, and blue, and green and violet being mixed or compound colors, some philosophers are opposed to it, and there are certain undoubted difficulties in the Young-Helmholtz explanation which still require solution."

*Practical Importance of Normal Color Sense.*— These are among the last words spoken on the subject by high authority. Indecisive as they are, they help, no doubt, in the direction of a true solution of the question. The practical significance of the subject is plain and must have been recognized to some slight extent for forty years. On the authority of Chamber's cyclopedia there was an examination in Edinburg in 1852 and 1853 of 1,154 persons, by Dr. Geo. Wilson. He found 65 of them color-blind. There were 21 who confounded red with green, and 19 who confounded brown with green. The

full importance of the subject, however, is only just beginning to be realized. Not till the regulations issued September 1st, 1887, was color-blindness considered a disability incapacitating a candidate for a commission as an officer in the British army. Longmore, who is authority for this statement, has given what is perhaps the most complete list of the classes whose color sense should be normal in order to prevent accidents resulting from their confounding colors, as pilots, engineers and signal office men are almost sure to do if color-blind. He says, "this affection is very important as regards those who have to depend on colored signs for guidance, such as signal officers, look-out men at sea and railway officials, or as chemists and others concerned in practical analysis, in which the presence of particular ingredients is determined by such tests as colored solutions, or by the effects produced so far as color is concerned; as regards physicians in the diagnosis of certain diseases characterized by color, as scarlatina; and even as regards officers in general command who require to be able to recognize clearly and quickly the colors of uniforms." This passage shows how color-blindness may cause disasters at sea and in the railway service, poisoning at the hands of druggists, and blunders in diagnosis by physicians resulting in death. The significance of the question and the abundance of interesting statistics and other material at hand tempt one to enlarge upon it unduly. But we are aiming to give a general survey of the subject as viewed by specialists and so repress the tendency to amplify and conclude the present phase of the question with an extract from Dr. Wolfe: "Seeing that the peculiarity of most color-blind people is to mistake red for green, or to ignore a certain shade of red altogether, and to take green for yellow, the subject assumes a practical importance in connection with railway signals, and lights in sailing vessels, steamers and lighthouses. The significance

of railway signals is as follows: At night a red light signifies "danger"; a green light, "caution" or "not sure"; and a white, "proceed." In the daytime red semaphores are used. When at a right angle to the post the signal means "danger"; at forty-five degrees, "proceed cautiously"; and when folded in, "road clear." By the regulations of the Board of Trade, every sailing vessel must, from sunset to sunrise, carry a green light on the right or star-board side, and a red light on the left or port side; and steamers must have, in addition, a white light at the masthead. This last is visible for five miles, and the side lights for two and a half miles' distance. The rule for meeting vessels is to keep red to red, and green to green. The colors indicate to the officer on duty the direction in which the ship is proceeding, and the relative position of both vessels. In lighthouses there are, generally, revolving and intermitting white lights, sometimes red ones, rarely green.

"The practical bearing of this question, therefore, is that red and green being of necessity the very colors used in railways, sailing vessels, and steamers, as well as in lighthouses, a color-blind person may be the engineer of a train running a mile a minute, and the passengers' lives depend upon his clear perception of the difference between a red and a green light. He may mistake the danger signal red for grey or white, or when it appears black he may not see it at all; and he may take green for the yellow or safety signal. Or he may be the pilot on a steamer, and cannot say whether the light directly ahead of him is red or green, and hence cannot steer so as to avoid a collision."

*Test for Color-blindness.*— One other feature of the subject remains to be treated. It is of greater practical interest to the oculist and optician than what has preceded. It relates to the proper test for color-blindness.

Colored test types were prepared by Snellen, and it was supposed the patient could be tested by having him name the colors as they appeared to him. For obvious reasons this proved unsatisfactory. It furnished no reliable criterion. The patient's color sense might be normal and yet his knowledge of the names of colors be very deficient. Hesitation and embarrassment on his part would be almost inevitable and the examiner would naturally construe it as betraying dullness of color perception even where the slightest trace of color-blindness was not present. On the other hand the examiner might be misled in the opposite direction by a real subject of color-blindness who had learned the names of the colors and how to discriminate between them by differences in their intensity. What is known as the Holmgren test, developed by a Swedish professor of that name, has now come into general use. It subjects the patient to a test as to his ability, not to designate, but to match colors. There is employed for this purpose colored skeins of worsted of the various colors of the spectrum, together with purple, brown, rose, gray, greenish-blue and yellowish-green; also several shades of each color and various tints of each shade of color. The examiner takes one of the skeins and asks the person tested to select other skeins which most resemble it. One who is color-blind will hesitate and make mistakes in matching the colors. Following up the tests determination is made as to whether there is simply a dullness of color-sense or whether achromatopsy is actually present, and if so what the colors are to which one may be blind. The test should be by daylight, not in artificial light. It is customary to begin with green and shades of green, then yellow, then blue, then red. Dr. Wolfe states that Dr. Stilling is the only writer who does not think this reliable and he holds the same opinion himself. He does not regard "this test of any value at all" unless the color

matched is seen at a distance. Possibly he is too confident. Perhaps he would tolerate the term "reliable" in place of denying "any value at all." His language is certainly very strong. But it suggests an important precaution,—the wisdom of making the test at a distance. He goes on to say, "After having tested a large number in the usual way, I had to abandon it, and resorted to examination in the following manner: First, the person looked through a spectroscope and was then asked to pick out from a heap of colored worsted the exact colors he saw in it; next, he was asked to match colors held up, one after another, at a distance of six feet from him. I have no hesitation in saying that this test is perfectly reliable."

An instrument devised by Dr. Thomson of Philadelphia so simplifies the application of the Holmgren test that it can be used in all ordinary cases, it is said, by any person of intelligence. In the naval schools of France a lantern test in artificial light is employed on the same principles. The examiner holds a lantern in his hand provided with a series of glasses which he can shift in such a way as to produce different colored lights. The person tested also holds a lantern of the same kind, and is requested to match the colors produced, the same as is done in the Holmgren test with different colored wools.

## LESSON XIII.

### Construction of Test Type.

In Lesson IV brief reference was made to test type and their use in determining acuteness of vision. We explained that the principle upon which they are constructed is that an object, in order to be visible to the normal eye, must be large enough to extend at least across an arc subtending 1′ of the given circle. That is, that the rays proceeding toward the eye from the extreme edges of an object must form an angle of at least 1′, in order that the image of the object may be large enough to produce a perceptible impression upon the retina; and of 5′ to be recognized clearly and steadily and observed or read with continued comfort. Figure 9, Lesson IV, illustrates this idea and also how the greater the distance of the object the larger must be its size if it is to fill the same angle, the largest distant object, C, filling no more angular space than the smaller one, B, or the smallest one, A.

Before presenting practical examples showing the use of test type in fitting the eye, (for reading and for distance, as will be done in next lesson), it will be of interest to look a little more closely into the principle governing the construction of test type and note the application of the principle in determining the varying sizes that type must be made to be clearly seen at the varying distances corresponding therewith. The elementary principle will not escape us, of course, that the size of the angle depends solely on the degree of divergence between the two lines forming it,—that the letters, A, B, and C, all extend across and fill the same identical angle, although the letters themselves vary in size.

First, then, let it be noted that the principle is not an intuitive or deductive one. It was settled solely by experiment. Continuous observation convinced Snellen and has satisfied others that a normal eye cannot discern an object unless it extend across an angle of at least $1'$ of space, and, farthermore, that to hold it in the vision steadily, with comfort and clearness, the object needs to be five times as large, or $5'$ across. Now the question is how to determine what should be the size of an object, according to this principle, at any given distance. We will try to answer.

Let us suppose the object is located 14 inches from the eye, the average reading distance customarily given. That distance is the radius of a circle whose diameter is 28 inches, and its circumference, found by multiplying 28 by 3.1416, is seen to be 87.964 inches. The circumference of every circle, large or small, is divided into 360° and each degree into $60'$, giving 21,600 as the number of minutes in the entire circle. Dividing the number of inches in the circle by the number of minutes in it, gives the width of $1'$ as .004 ($\frac{4}{1000}$) of an inch. That is in a circle whose radius is 14 inches, an arc of $1'$ is .004 of an inch wide. This, therefore, is the width of a discernible object at 14 inches, and 5 times that space, .020 of an inch, is the width of an object or of letters large enough to be steadily recognized or read with comfort. Accordingly, Snellen makes each line in his test letters $1'$ wide, and each letter itself $5'$ in width. By the same rule we can determine the size of letters needed to test at any distance, 20 inches or 20 feet.

Suppose one wanted his work, if a mechanic, at 24 inches distant; or his manuscript, if a minister, at the same distance. An arc of $1'$, in that case, would embrace .007 of an inch, and an arc of $5'$, .035 of an inch. At 12 inches from the eye $1'$ gives a width of .0036 of an

inch, and 5′ embrace an object .018 of an inch in width. If sewing or otherwise engaged on fine work, one may need to hold it as near as 12 inches from the eye. Some would hold it still nearer. At 12 inches 1′ requires an object of the width of .0036 of an inch, and 5′, an object .018 of an inch wide. Custom has designated 14 inches as the average reading distance. At that distance 1′ embraces a space of .004 of an inch. To be read with comfort, letters must therefore cover 5 times that space, and so be .020 inch in size. Many persons naturally hold their reading beyond this point. This fact might be expressed by designating 16 inches from the eye the outer limit of the average reading distance. At 16 inches, 1′ covers an arc of .0046 of an inch, and 5′ an arc of .023 of an inch. At 20 inches 1′ covers an arc of .0058 of an inch, and 5′, an arc of .030 of an inch.

For some time we have questioned if 14 inches does not fall short of the average reading distance. Examining factory employes recently strengthened this opinion. Believing that 15 inches come nearer the truth, we have named that the *Johnston average reading distance*, and so have omitted 14 inch type from our grades of reading type. At 15 inches the arc embraced by 1′ is .00436 of an inch in width. That space multiplied by 5 gives the needed size of letters as .022 of an inch.

We call attention to the fact that our *reading test card* and *distance test letters* in common use, present a continuous and quite regularly ascending scale of distances. The reading card begins with 12-inch test letters and regularly increases each added distance till it concludes with 108-inch (9-foot) letters. At this point distance charts begin with 10-foot type and end with 50 to 200-foot type.

We conclude with all the type required to test the average eye for reading, showing sizes of type and distances at which to use them, according to the above principles for constructing test type. The eye when normal in its

refraction, or when rendered so artificially by the aid of lenses, and all presbyopia likewise corrected, would see the letters below at the respective distances indicated, were no defect in visual acuteness ever present. But on this account we must bear in mind that in presbyopia, as in other defects, if the eye cannot be brought up with lenses to the normal standard, all that can be done is to bring it up as near as possible. If 15-inch type, for example, cannot be rendered comfortably distinct at that distance, the only alternative may be to use a stronger lens and hold the same type only 14 inches distant. Acuteness may be so poor that 20 or 24-inch or even larger type may have to be used at the average reading distance, nothing smaller answering.

12 INCH TYPE. BRILLIANT.

Near distance for fine work. The measure of this type is twenty thousandths of an inch. The normal or corrected eye, with average acuteness, should read it at a distance of twelve inches.

15 INCH TYPE.—No. 1 Jaeger. DIAMOND.

Johnston average reading distance. The size of this type is twenty-two thousandths of an inch. If the eye is normal, or has been properly corrected, this type should be read at fifteen inches.

20 INCH TYPE. PEARL.

Near pulpit or mechanic's distance. The size of this type is thirty thousandths of an inch. If the eye is normal, or has been properly corrected, this type should be read at twenty inches.

24 INCH TYPE. NONPAREIL.

Average pulpit or mechanic's distance. This type is thirty-five thousandths of an inch in size, and should be read by the normal or corrected eye at twenty-four inches.

30 INCH TYPE.—No. 4 Jaeger. AGATE.

Far pulpit or mechanic's distance. The distance at which this type should be read is thirty inches. It is forty thousandths of an inch in width.

32 INCH TYPE.—No. 2 Snellen, No. 5 Jaeger.
BREVIER OLD.
To be read at a distance of thirty-two inches. Size of type, forty-five thousandths of an inch.

35 INCH TYPE.—No. 3 Snellen, No. 7 Jaeger.
BREVIER MOD.
To be read at thirty-five inches. Size of type fifty thousandths of an inch.

56 INCH TYPE.—No. 4 Snellen, No. 11 Jaeger.
PICA.
This type is eighty thousandths of an inch in size, and should be read at a distance of fifty-six inches.

72 INCH TYPE.—No. 5 Snellen, No. 13 Jaeger.
GT. PRIMER.
The size of this type is one hundred and five thousandths of an inch in width, and should be read at 72 inches.

108 INCH TYPE.—No. 7 Snellen, No. 14 Jaeger.
2 LINE SMALL PICA.
**This type sh'd be read at 108 inches. Size of type 157 thousandths of an inch.**

## LESSON XIV.

### How to Fit the Eye, Practically Illustrated.

*Abbreviations.*— Brevity, simplicity, uniformity, and comprehensiveness are desirable in giving results obtained in testing and fitting an eye. One or more, and oftenest, all these features are found lacking in the efforts of operators to communicate the results of an examination. The writer submits, in the examples following, what he supposes to be the most comprehensive set of symbols yet presented. So far as possible he has adopted forms already in use. In enlarging on them some variations were necessary to avoid ambiguity.

These abbreviated forms will prove very convenient where the operator desires to preserve a record, and even more so, when he desires to communicate to the manufacturing optician, as often occurs, the various steps in his tests.

Having made the casual diagnosis and prognosis of a case, by observing appearances, the first series of steps to be taken in examining an eye is to test its natural or naked vision. To designate this unaided vision, we use the abbreviation N. v. (V. is often used to indicate simply vision under given conditions. If these conditions are such as determine visual acuteness, then the V. found will equal V. a. Otherwise the two will not be equal.)

The second series of steps is testing with trial lenses. To abreviate this we use Tl. for trial. The last step is to decide upon the proper prescription, using the abbreviation, Presc., or ℞, the more common symbol for recipe. The sign for equality (=) stands for "equals" or "shows"

or "indicates" or "amounts to" or "suggests" or "seems," whichever expression states most correctly the meaning of the sign in the particular connection in which it is used. A bracket or the following equivalent sign (<) means "to enlarge" upon the test, the spaces set off between these bracket signs, thus showing the different stages of progress in the test.

In an abbreviation where one word is used, we have, as far as practicable, employed the first letter of the first and second syllables; where two words, the first letter of each.

With these explanations the following list of abbreviations will become clear. Although some have been previously used, we now put them all together for the convenience of the reader.

R. or R. E., or O. D., = *Oculus Dexter*, = Right Eye.
L. or L. E., or O. S., = *Oculus Sinister*, = Left Eye.

| | | |
|---|---|---|
| O. U. | = | *Oculi Unati*, = Both Eyes together. |
| N. v. | = | Naked vision. |
| V. | = | Vision. |
| D. t. | = | Distance test. |
| R. t. | = | Reading test. |
| Rd. | = | Read, reads or reading. |
| Em. | = | Emmetropia. |
| Pb. | = | Presbyopia. |
| Am. | = | Ametropia. |
| Hp. | = | Hypermetropia. |
| Mo. | = | Myopia. |
| As. | = | Astigmatism. |
| Sb. | = | Strabismus. |
| An. | = | Anisometropia. |
| Ab. | = | Amblyopia. |
| Nph. | = | Nephelopia. |
| Ath. | = | Asthenopia. |
| V. a. | = | Visual acuteness. |
| Ty. | = | Type. |
| Dist. | = | Distance. |
| N. p. | = | Near point. |
| W. p. | = | Working point. |
| D. p. | = | Distance point. |
| A. a. | = | Accommodative acuetness. |
| Ac. | = | Accommodation. |

The use of a cypher indicates the absence of the particular difficulty mentioned.

### Examples in Simple Pb.

*No. 1.*— Mrs. A. E., age about 40; complains of weakness of eyes; dim V. in evening; has to hold reading beyond usual distance; can read fairly well in day time.

$$\text{N. v.} \left\{ \text{O. U.} \left\{ \begin{array}{l} \text{D. t.} < \text{As.} = 0 < \text{V.} = \frac{20}{20} \\ \text{R. t.} < \text{N. p.} = \text{Pb.} \end{array} \right. \right.$$

The above preliminary test expressed in language instead of symbols would read about as follows: Testing the naked vision of the two eyes, we find them alike. The distance test shows an absence of astigmatism and the presence of normal vision. The reading test shows such a removal of the near point (and as a consequence, the working point, also, to a proportionate extent,) as to indicate presbyopia.

The final test or trial with lenses may be expressed as follows:

$$\text{Tl.} \left\{ \text{O. U.} \left\{ \begin{array}{l} + .25 \text{ Ds. improves V.} < +.5 \text{ Ds. still} \\ \text{better} < +.75 \text{ Ds. not so good} < \text{no} \\ \text{other number so good as } +.5 \text{ Ds.} \end{array} \right. \right.$$

We write the completed test, with the proper prescription formula, as follows:

℞ for Rd. for Mrs. A. E.
O. U. + .5 Ds.

*No. 2.*— Mr. J. E—, aged 50; has used glasses five or six years; says his spectacles "are growing too young for him."

$$\text{N. v.} \left\{ \text{O. U.} \left\{ \begin{array}{l} \text{D. t.} < \text{As.} = 0 < \text{V.} = \frac{20}{20} \\ \text{R. t.} < \text{N p.} = \text{Pb.} < \text{Rd.} \\ \quad \text{30 in. Ty. with difficulty.} \end{array} \right. \right.$$

$$\text{Tl.} \left\{ \begin{array}{l} \text{Each + No. up to 1.25 Ds. improves V.} \\ \quad \text{No other No. adds improvement.} \\ \quad \text{With it Rd. 12 Ty. at 12 in.} \end{array} \right.$$

℞ for Rd. for Mr. J. E—
O. U. + 1.25 Ds.

*No. 3*—M. E. S., aged 60; used glasses for 25 years; says present glasses are "going away from him."

N. v. $\begin{cases} \text{O. D.} < \text{D. t.} < \text{As.} = 0 < \text{V.} = \frac{20}{20} < \text{R. t.} = \text{Pb.} = 72 \text{ Ty. at } 15 \text{ in.} \\ \text{O. S.} < \text{R. t.} < \text{As.} = 0 < \text{V.} = \frac{20}{20} < \text{R. t.} = \text{Pb.} = \\ \quad 72 \text{ Ty. at } 15 \text{ in. with difficulty.} \end{cases}$

Tl. $\left.\begin{cases} \text{O. D.} + 3.75 \text{ Ds.} = 15 \text{ Ty. at } 15 \text{ in.} \\ \text{O. S.} + 4 \text{ Ds.} = 15 \text{ Ty. at } 15 \text{ in.} \end{cases}\right\} \text{V. a.} = \frac{20}{20}$

℞ for Rd. for Mr. M. E. S.
O. D. + 3.75 Ds.
O. S. + 4 Ds.

The language of the above symbols is, that the test for naked vision shows that astigmatism is absent, that distant vision is normal, being $\frac{20}{20}$, and that presbyopia is present to such an extent that the best the unaided eye can do is to read 72-inch type at 15 inches. The tests show the left eye weaker than the right, but with the proper correction it is brought up to a visual power equal to the right. Trial with lenses shows normal visual acuteness.

*No. 4.*—Mrs. L—, age 55; says her eyes are unlike; wants glasses for reading.

N. v. $\begin{cases} \text{O. D.} < \text{D. t.} < \text{As.} = 0 < \text{V.} = \frac{20}{20} < \text{R. t.} = 72 \text{ Ty. barely.} \\ \text{O. S.} < \text{D. t.} < \text{As.} = 0 < \text{V.} = \frac{20}{20} < \text{R. t.} = 108 \text{ Ty. plainly.} \end{cases}$

Tl. $\left.\begin{cases} \text{O. D.} + 3 \text{ Ds.} = 15 \text{ in. Ty.} \\ \text{O. S.} + 5 \text{ Ds.} = 15 \text{ in. Ty.} \end{cases}\right\} \text{V. a.} = \frac{20}{20}$

℞ for Rd. for Mrs. L—
O. D. + 3 Ds.
O. S. + 5 Ds.

These glasses restore binocular vision, but are at first used with difficulty because of their difference of refraction. Advised to persist in their use. Four weeks later showed that satisfactory binocular vision was established.

*No. 5.*—Mr. C. R. F., aged 60; never had glasses to suit.

$$\text{N. v.} \left\{ \begin{array}{l} \text{R.} < \text{D. t.} < \text{As.} = 0 < \text{V.} = \frac{20}{50} < \text{R. t.} = 9 \text{ ft. Ty.} \\ \text{L.} < \text{D. t.} < \text{As.} = 0 < \text{V.} = \frac{20}{70} < \text{R. t.} = 10 \text{ ft. Ty.} \end{array} \right.$$

$$\text{Tl.} \left\{ \begin{array}{l} \text{R.} + 4.50 \text{ Ds.} = 30 \text{ in. Ty.} \\ \text{L.} + 8 \text{ Ds.} = 56 \text{ in. Ty.} \end{array} \right\} \begin{array}{c} \text{Binocular} \\ \text{V.} \\ \text{unsatisfactory.} \end{array}$$

After several trials the following prescription was found to give satisfactory vision:

℞ for Rd. for Mr. C. R. F.
R. + 5 Ds.
L. + 6.5 Ds.

*No. 6.*—Mr. G. L. B—wants glasses for reading. He is 70 years of age.

$$\text{N. v.} \left\{ \begin{array}{l} \text{R.} < \text{As.} = 0 < \text{V.} = \frac{20}{50} < \text{R. t.} = 10 \text{ ft. Ty.} \\ \text{L.} < \text{As.} = 0 < \text{V.} = \frac{20}{100} < \text{R. t.} = 30 \text{ ft. Ty.} \end{array} \right.$$

$$\text{Tl.} \left\{ \begin{array}{l} \text{R.} + 5 \text{ Ds.} = 32 \text{ in. Ty.} \\ \text{L.} + 10 \text{ Ds.} = 72 \text{ in. Ty.} \end{array} \right\} \begin{array}{c} \text{Binocular V.} \\ \text{very} \\ \text{unsatisfactory.} \end{array}$$

℞ for Rd. for Mr. G. L. B—
R. + 6 Ds.
L. + 8 Ds.

Entirely satisfactory after using them for six weeks.

*No. 7.*—Mr. J. W. G., aged 60.

$$\text{N. v.} \left\{ \begin{array}{l} \text{R.} < \text{D. t.} < \text{As.} = 0 < \text{V. } \tfrac{20}{40} < \text{R. t.} = 10 \text{ ft. Ty.} \\ \text{L.} < \text{D. t.} < \text{As.} = 0 < \text{V. } \tfrac{20}{200} < \text{R. t.} = 50 \text{ ft. Ty.} \end{array} \right.$$

$$\text{Tl.} \left\{ \begin{array}{l} \text{R.} + 3.5 \text{ Ds.} = 30 \text{ in. Ty.} \\ \text{L.} + 7 \quad \text{Ds.} = 56 \text{ in. Ty.} \end{array} \right\} \text{V. a.} = \tfrac{20}{20}$$

But for comfortable binocular V. he was obliged to use the following presc.:

℞ for Rd. for Mr. J. W. G.
R. + 3.5 Ds.
L. + 5 Ds.

*No. 8.*—Mr. H. J. R., aged 68; complains that he can see only with right eye.

$$\text{N. v.} \left\{ \begin{array}{l} \text{R.} < \text{As.} = 0 < \text{V.} = \tfrac{20}{50} < \text{R. t.} = 10 \text{ ft. Ty.} \\ \text{L.} < \text{As.} = 0 < \text{V.} = \tfrac{5}{200} < \text{R. t.} = 200 \text{ ft. Ty.} \end{array} \right.$$

Lenticular cataract visible in L. E.

Tl. { R. + 5 Ds. =32 in. Ty.
L. cannot be improved; gave + 5 Ds., as it was as good as any, and as it balanced the other in weight and appearance, it was better.

℞ for Rd. for Mr. H. J. R.
O. U. + 5 Ds.

*Comments.*—Visual acuteness (V. a.) can be determined with certainty only by using lenses. Hence it is indicated in connection with the trial. To indicate the apparent condition of vision in the test for N. v. we use simply V. It is immaterial whether the test for astigmatism (As.) be made first or later. We have placed it first as it is natural to start off with a question about the appearance

of the radiating lines. In the trial with lenses it is best to test for distance first, and so the natural place for recording V. a. is first, but, if more convenient, it may be recorded later. A test shown under N. v. may be assumed made under Tl. even if its record is not down in detail in latter test, or except by inference. For example, if in the Tl. V. a. $= \frac{20}{20}$, it shows by inference that ametropia is absent, (Am. $= 0$), and astigmatism also, that being included in ametropia. And that confirms the apparent As. $= 0$, shown under N. v. In cases of simple Pb., like the above, the trial for V. a. with even the weakest lens will blur the vision. If thorough trial with both positive and negative lenses is made it will be shown that Am. $= 0$. If without the lenses the eye can read 20 Ty. at 20 ft., the V. a. $= \frac{20}{20}$, and can be shown with N. v. In all other cases, Am. being present, the V. a. can be determined only when the proper correcting lens is before the eye.

The sure way to fit an eye is to make the trial with lenses as above. But the careful operator is glad to avail himself of additional methods that may assist in verifying his results. The table giving the ages at which various refractive powers are required in an emmetropic eye, *page* 76, has a measure of value. The same is true of the table, *page* 73, showing the amplitude of accommodation at different ages. If we could know just how much amplitude was needed, in a given case, for continuous work, and how much to be kept in reserve, we could approximate closely to the power of the lens that might be needed. Taking Landolt's data, that the near point is 22 centimeters from the eye at forty years, our estimate, in treating the question under presbyopia, was, that nearly half the accommodation would need to be kept in reserve in continuous work, or, stated in exact figures, 45%, leaving 55% for work. The low average vigor of the overtaxed vision of our day, suggests the need of a liberal margin to make the rule safe. But Landolt thinks the

eye can get along with a less reserve, varying from one-third to one-quarter, leaving from 66% to 75% for work. The range of probability is too wide to make the data of more than approximate value, and yet they educate the operator to a better knowledge of the capacity of the eye.

If the eye needs to reserve half its capacity when working, as we assumed in discussing presbyopia, then the working point needs to be twice the distance of the near point. If a reserve of one-third its capacity will do, then the working point needs to be no more than 50% beyond the near point. If this would throw the working point inconveniently far away, a lens must be provided for the eye which will bring the working point back to a convenient distance. For instance, suppose the near point of a given eye was 10 inches, then, by the rule above, its working point would be 15 inches; but suppose it was desired to make its working point 12 inches, what lens would have to be used?—and how shall we find it?

We find the working point by adding to 10 inches (the near point) 50% of itself, which gives us 15 inches. That means that an eye must work, unaided by a lens, at no less than 15 inches. But 12 inches is the desired working point. It is evident that the differencc between a 12-inch lens and a 15-inch lens will give a power sufficient to carry the focus back over this three-inch distance—from the 15-inch to the 12-inch point. The difference between $\frac{1}{12}$ and $\frac{1}{15}$ gives $\frac{1}{60}$. That is, a 60-inch lens will enable the given eye to work at 12 inches.

In the same way, the working point can always be determined, and, also, the lens required by a given eye for a given working point.

The rules may be expressed as follows:

*To find the working point of a given eye, increase its near point by* 50 *per cent. of itself. To find what lens will*

*be required for a given working point, find the difference between the refractive powers represented by the given working point desired, and the working point at which the eye is capable of working unaided.*

That the above rule and illustration reserve one-third of the refractive power in work, will be manifest on a little reflection. To find the working power at 15 inches, we have added 50% of itself to the near point at 10 inches. In removing the reading from 10 inches to 15 inches, it is evident that we relieve the eye of a refractive effort equal to the difference between $\frac{1}{10}$ and $\frac{1}{15}$ which is $\frac{1}{30}$, and so we reserve that amount of its working force. Now, what part of its maximum refraction, $\frac{1}{10}$, is the $\frac{1}{30}$ which is reserved? Plainly, one-third, which is the very portion to be reserved according to the principle and rule.

Observing these and other expedients for approximating and so verifying the results of one's tests, will not only protect against error, but greatly increase one's certainty and assurance, and his facility and success proportionately.

Facility is promoted when you are undecided whether the lens before the eye is correct, by delaying to exchange it for another and instead increasing its strength by a + ¼ Ds., or + ½ Ds., held in front of it, and then diminishing it by a — ¼ Ds., or a — ½ Ds. If neither is an improvement, you have the right lens.

As implied in the preceding, one of the first things to do in testing simple presbyopia is to see what the N. p. is, with N. v. If it is beyond the normal distance for forty years of age, viz., from 8¾ to 9 inches from the eye, that fact suggests presbyopia. In making this test an additional pointer can be obtained by noticing what the acuteness is at the near point, (not the visual acuteness, for that can be found only when accommodation is relaxed and so at 20 feet, and usually with lenses), but what we might call the a. a. (accommodative acuteness).

If, for illustration, the 72-inch type cannot be seen till brought within 12 inches of the eye, it shows accommodative acuteness $\frac{1}{6}$ normal vision; if not till brought 9 inches from eye, a. a. would be $\frac{1}{8}$, and so on. This condition should lead one to look for hypermetropia. When the proper lenses have been fitted before the eyes, the near point may be expected to be at the normal distance.

### Examples in Simple Hypermetropia.

*No. 1.*— Miss C. R., age 10; complains of weak eyes.

N. v. { D. t. $= \frac{20}{20}$ (because of Ac.)
R. t. $=$ 12 in. Ty.

Tl. { O. U. { D. t. $=$ Am. $<$ As. $= 0 <$ V. a. $= \frac{20}{20}$
Either $+.5$ Ds. or $+.75$ Ds. or $+ 1$ Ds $= \frac{20}{20}$, (because Ac. adjusts itself to each respective power), but $+ 1.25$ Ds. dims V. (farther adjustment by relaxation of ciliary being impossible).
Hp. $=$ 1 Ds.
R. t. $=$ 12 in. Ty.

℞ for Dist. and Rd. for Miss C. R.
O. U. $+ 1$ Ds.

In a young hypermetrope the same pair is suitable for both distance and reading. In communicating to a manufacturing optician a series of trial tests, comments, like the above in brackets, are unnecessary. He will understand from the tests alone. We insert the explanations for the sake of the beginner.

*No. 2.*— Mrs. M. B—, age 27; can neither read nor sew for more than ten minutes at a time. Eyes did not give trouble till a year since, when she did considerable reading; do not trouble at a distance, but near by, and, also, cannot bear a bright light because of pain it causes.

$$\text{N. v.} \left\{ \begin{array}{l} \text{O. D.} < \text{D. t.} = \frac{20}{20} < \text{R. t.} = 12 \text{ in. Ty.} \\ \text{O. S.} < \text{D t.} = \frac{20}{30} < \text{R. t.} = 15 \text{ in. Ty.} \end{array} \right.$$

$$\text{Tl.} \left\{ \begin{array}{l} \text{O. D.} + 2.25 \text{ Ds.} = \frac{20}{20} < + 2.50 \text{ Ds. blurs V.} \\ \text{O. S.} + 2.75 \text{ Ds.} = \frac{20}{20} < + 3 \text{ Ds. blurs V.} \\ \text{As.} = 0. \end{array} \right.$$

℞ for Dist. and Rd. for Mrs. M. B—.

O. D. + 2.25 Ds.

O. S. + 2.75 Ds.

No trouble is felt in looking at a distance, because the accommodative effort it requires was not sufficient to produce conscious strain; but the fact that it requires any effort whatever, proves the need of glasses. Being under 40, her distance lenses are correct for reading. In the Tl. the use of $\frac{20}{20}$ shows the test is made at 20 ft., and so also is the enlargement ($<$) upon it. The test for As. is the same, as are all tests for ametropic conditions.

*No. 3.*—Mr. J. F. S., aged 30; had been wearing + 7 Ds. for six years, but never could see at any distance satisfactorily; eyes had always been weak; after reading a few minutes the print becomes indistinct and blurred; frequent pains in head; often obliged to wear smoked glasses to protect eyes from light.

$$\text{N. v.} \left\{ \begin{array}{l} \text{O. D.} < \text{D. t.} = \frac{20}{50} < \text{R. t.} = 72 \text{ in. Ty.} \\ \text{O. S.} < \text{D. t.} = \frac{20}{70} < \text{R. t.} = 108 \text{ in Ty.} \end{array} \right.$$

$$\text{Tl.} \left\{ \begin{array}{l} \text{R.} + 9 \text{ Ds.} = \frac{20}{20} < \text{R. t.} = 12 \text{ in. Ty.} \\ \text{L.} + 9 \text{ Ds.} = \frac{20}{80} < \text{R. T.} = 15 \text{ in. Ty.} \end{array} \right.$$

V. a. of L. E., inferior; cannot be made normal.

As. of O. U. = 0.

℞ for Dist. and Rd. for Mr. J. F. S.

O. U. + 9 Ds.

## Hypermetropia Associated with Presbyopia.

*No. 1.*—Mr. C. B. L., aged 38; always had weak eyes, and for the last six months sight has been failing for reading.

$$\text{N. v.} \begin{cases} \text{O. D.} < \text{D. t.} = \frac{20}{80} < \text{R. t.} = 20 \text{ in. Ty.} \\ \text{O. S.} < \text{D. t.} = \frac{20}{40} < \text{R. t.} = 30 \text{ in. Ty.} \end{cases}$$

$$\text{Tl.} \begin{cases} \text{O. D.} < \text{D. t.} + 1 \text{ Ds.} = \frac{20}{20} < \text{R. t.} = 12 \text{ in. Ty.} \\ \text{O. S.} < \text{D. t.} + 1.5 \text{ Ds.} = \frac{20}{20} < \text{R. t.} = 12 \text{ in. Ty.} \end{cases}$$

$$\text{Am.} = \text{Hp.} < \text{As.} = 0 < \text{R. t.} = \text{Pb.}$$

℞ for Dist. for Mr. C. B. L.
O. D. + 1 Ds.
O. S. + 1.5 Ds.

℞ for Rd. for Mr. C. B. L.
O. D. + 1.5 Ds.
O. S. + 2 Ds.

Prescribe two pairs, or else bifocals, as patient may prefer. Presbyopia is premature.

*No. 2.*—Mr. E. G. K. "wants one pair of glasses for all distances."

$$\text{N. v.} \begin{cases} \text{R.} = \frac{20}{80} \text{ and } 9 \text{ ft. Ty.} \\ \text{L.} = \frac{20}{100} \text{ and } 10 \text{ ft. Ty.} \end{cases}$$

$$\text{Tl.} \begin{cases} \text{R.} + 5 \text{ Ds.} = \frac{20}{80} < \text{R. t.} + 7 \text{ Ds.} = 24 \text{ in. Ty.} \\ \text{L.} + 7 \text{ Ds.} = \frac{20}{40} < \text{R. t.} + 9 \text{ Ds.} = 32 \text{ in. Ty.} \end{cases}$$

$$\text{Am.} = \text{Hy.} < \text{As.} = 0 < \text{R. t.} = \text{Pb.}$$

℞ for Dist. for Mr. E. G. K.
R. + 5 Ds.
L. + 7 Ds.

℞ for Rd. for Mr. E. G. K.
R. + 7 Ds.
L. + 9 Ds.

Prescribe bifocals.

In anisometropic eyes the rule is that the same ratio of increase will be required by each in passing from the distance to the reading lenses, as occurs above.

When possible, it is just as well to vary or abbreviate your formulas as we have done in some of the above tests. The only necessity is to make your tests understood and brief. General uniformity is desirable, and yet it need not be slavish.

In fitting Hp. there is little danger of over-correction; the frequency of latent Hp. makes under-correction much more likely. The test needs to be repeated at intervals to see if additional latent Hp. has become manifest.

Likewise, in Pb., contrary to a common supposition, there is rather more danger of under than over-correction, provided, at least, that due regard is had to the proper range of accommodation needed. If the selected lens or lenses bring the n. p. to the proper distance and place the w. p. where the person's occupation requires it, the ℞ may be pronounced correct. When nothing is said or shown to the contrary, the giving of the size of Ty. indicates that the test was made at the average reading distance, the same as the fraction with 20 for the numerator shows that the test is made for distance.

## Examples in Simple Myopia.

*No. 1.*— Mrs. C., aged 25; book-keeper; has used eyes continuously for near work for two years. Pains in eyes for last two months; they soon weary; cannot see clearly at a distance.

$$\text{N. v.} \begin{cases} \text{R.} < \text{D. t.} = \frac{20}{40} < \text{As.} = 0 < \text{Rd. 12 Ty. at 10 in.} \\ \text{L.} < \text{D. t.} = \frac{20}{40} < \text{As.} = 0 < \text{Rd. 12 Ty. at 10 in.} \end{cases}$$

$$\text{Tl.} \begin{cases} \text{R.} < -\tfrac{1}{2}\,\text{Ds.} = \frac{20}{30} < -\tfrac{3}{4}\,\text{Ds.} = \frac{20}{30} < -1\,\text{Ds.} = \frac{20}{20}. \\ \text{L.} < -\tfrac{1}{2}\,\text{Ds.} = \frac{20}{30} < -\tfrac{3}{4}\,\text{Ds.} = \frac{20}{30} < -1\,\text{Ds.} = \frac{20}{20}. \end{cases}$$

D. t, of O. U. also gives $\frac{20}{20}$ with any cc. lens from $-1$ Ds. to $-1\frac{3}{4}$ Ds., (because Ac. can neutralize the increased refraction), but they make Ty. look smaller. Hence we give the weakest that $= \frac{20}{20}$, and thus restore normal vision.

D. t. = Am. = Mo.

℞ for Dist. and Rd. for Mrs. C.
O. U. $-1$ Ds.

*No. 2.*—Miss M. M., aged 22. Wants a pair of eye-glasses; complains of "very poor sight for distance"; no pain nor weakness of eyes; they feel perfectly strong.

$$\text{N. v.} \begin{cases} \text{R.} < \text{D. t.} = \frac{20}{200} < \text{As.} = 0 < \text{Rd. 12 Ty. at 5 in.} \\ \text{L.} < \text{D. t.} = \frac{10}{200} < \text{As.} = 0 < \text{Rd. 15 Ty. at 3 in.} \end{cases}$$

Tl. {
R. $< -2$ Ds. $= \frac{20}{100} < -3$ Ds. $= \frac{20}{50} < -3\frac{1}{2}$ Ds. $= \frac{20}{30} < -4$ Ds. $= \frac{20}{20}$.
L. $< -3.5$ Ds. $= \frac{20}{200} < -4$ Ds $= \frac{20}{100} < -5$ Ds. $= \frac{20}{50} < -5.5$ Ds. $= \frac{20}{50} < -6$ or 7 or 8 Ds. $= \frac{20}{30}$.
But the last three numbers make 20 ft. letters look smaller. The probable presence of retinal opacity or disease (amblyopia) prevents farther improvement.

D. t. = Am. = Mo.

℞ for Dist. for Miss M. M.
R. — 4 Ds.
L. — 6 Ds.

℞ for Rd. for Miss M. M.
R. — 2 Ds.
L. — 4 Ds.

Being unable to restore the L. E. to normal V., we lift it as high as possible, to $\frac{20}{50}$, which puts it into companionable relations with the R. E. The decrease in the power of cc. lenses required in going from Dist. to Rd. Nos. should uniformly be of the same ratio before both eyes, as illustrated in the last example.

*No. 3.*— Mr. R. E. F., aged 35. Clerk. Has worn glasses since 10 years of age; present glasses don't suit; eyes tire very soon when reading.

$$\text{N. v.}\begin{cases}\text{R. E.} = \frac{8}{200} < \text{As.} = 0 < \text{Rd. 20 Ty. at 3 in.}\\ \text{L. E.} = \frac{5}{200} < \text{As.} = 0 < \text{Rd. 20 Ty. at 2 in.}\end{cases}$$

$$\text{Tl.}\begin{cases}\text{R. E.} < -8\text{ Ds.} = \frac{20}{200} < -10\text{ Ds.} = \frac{20}{200}\\ \quad < -11\text{ Ds} = \frac{20}{50} < -12\text{ Ds.} = \frac{20}{30}.\\ \text{L. E.} < -8\text{ Ds} = \frac{10}{200} < -10\text{ Ds.} = \frac{20}{200} <\\ \quad -12\text{ Ds.} = \frac{20}{200} < -13\text{ Ds.} = \frac{20}{50}\text{, poorly.} <\\ \quad -14\text{ Ds} = \frac{20}{50}\text{ clear.} \quad < -15\text{ Ds.} = \frac{20}{50}\text{,}\\ \quad \text{but smaller Ty.}\end{cases}$$

℞ for Dist. for Mr. R. E. F.

R. E. – 12 Ds.

L. E. – 14 Ds.

℞ for Rd. for R. E. F.

R. E. – 9 Ds.

L. E. – 11 Ds.

## Example of Myopia with Pb.

*No. 1.*— Mrs. H. E. C., aged 58. Has "always been a little near sighted, but never used glasses." Cannot see to read, especially at night, at what has been her usual reading distance.

$$\text{N. v.}\begin{cases}\text{R.} < \text{D. t.} = \frac{20}{50} < \text{As.} = 0 < \text{Rd. 24 Ty. at 10 in.}\\ \text{L.} < \text{D. t.} = \frac{20}{50} < \text{As.} = 0 < \text{Rd. 24 Ty. at 10 in.}\end{cases}$$

$$\text{Tl.} \begin{cases} \text{R.} < -1 \text{ Ds.} = \frac{20}{30} < -1\frac{1}{4} \text{ Ds.} = \frac{20}{80} \\ \quad < -1\frac{1}{2} \text{ Ds.} = \frac{20}{20} \\ \text{L.} < -1 \text{ Ds.} = \frac{20}{30} < -1\frac{1}{2} \text{ Ds.} = \frac{20}{20} \end{cases}$$

D. t. = Am. = Mo.

Her Mo. being small we suspect from her age that she may have Pb. and so make a test at the reading distance with plus lenses as follows:

$$\text{O. U.} \begin{cases} < \text{R. t.} + \frac{1}{4} \text{ Ds.} = 20 \text{ Ty.} < + \frac{1}{2} \text{ Ds.} = \\ \quad 15 \text{ Ty.} < + \frac{3}{4} \text{ Ds.} = 12 \text{ Ty. (distinct at} \\ \quad 8 \text{ to } 10 \text{ inches.)} \end{cases}$$

℞ for Dist. for Mrs. H. E. C.

O. U. — 1½ Ds.

℞ for Rd. for Mrs. H. E. C.

O. U. + ¾ Ds.

## Examples in Simple Astigmatism.

*No. 1.*—Miss R. M. H., aged 13. Complains of weak eyes; "they grow tired in a short time when reading; have been weak for past year.

$$\text{N. v.} \begin{cases} \text{O. D.} < \text{D. t.} = \frac{20}{30} < \text{As.} = 180^\circ < \text{R. t.} \\ \quad = 12 \text{ in. Ty. poorly.} \\ \text{O. S.} < \text{D. t.} = \frac{20}{30} < \text{As.} = 180^\circ < \text{R. t.} \\ \quad = 12 \text{ in. Ty. poorly.} \end{cases}$$

$$\text{Tl.} \begin{cases} \text{O. U.} < \text{Hp.} = 0 < \text{Mo.} = 0., \text{ no } + \text{ or } - \text{ Sph.} \\ \quad \text{lens giving improvement.} \\ \text{O. U.} < + \frac{1}{2} \text{ Dc. ax. } 180^\circ = \text{best result.} \end{cases}$$

℞ for Dist. and Rd. for Miss R. M. H.

O. U. + ½ Dc. ax. 180°

*No. 2.*—Mr. J. F. N., aged 26. Complains of very poor sight for past five years, especially in left eye, which often gives pain and is inflamed. Dates his troubles from serious illness with typhoid fever over five years previous.

N. v.
R. < D. t. = $\frac{20}{40}$ < As. = 70° < R. t. = Rd. 24 Ty. poorly.
L. < D. t. = $\frac{20}{200}$ < As.= 125° < R. t. = Rd. 15 Ty. at 12 in.

Tl.
O. U. < Hp. = 0 < Mo. = 0.
R. E. < + ½ Dc. ax. 70° dims V. < – ½ Dc. ax. 70° improves V. < – 1½ Dc. ax. 70° neutralizes As. and gives $\frac{20}{20}$ < R. t. = 12 Ty.
L. E. < – 2¾ Dc. ax. 125 reduces As. to 0, and gives $\frac{20}{100}$ < R. t. = 72 Ty. poorly. Atrophy of optic nerve and retina prevents better results.

℞ for Dist. and Rd. for Mr. J. F. N.
R. E. – 1½ Dc. ax. 70°
L. E. – 2¾ Dc. ax. 125°

## Examples in Compound Astigmatism.

*No. 1.*—Mr. H. R. L., aged 30. Cannot see very well in the distance, and cannot read without glasses.

N. v.
R. < D. t. = $\frac{20}{50}$ < As. = 150° < R. t. = 20 Ty.
L. < D. t. = $\frac{20}{50}$ < As. = 50° R. t. = 20 Ty.

Tl.
R. < + 1½ Ds. = $\frac{20}{30}$ < As. = 150° > < ⊃ + ½ Dc. ax. 150° = As. 0 < V a. = $\frac{20}{20}$
L. < + 1¾ Ds. = $\frac{20}{30}$ < As. = 50° > < ⊃ + ½ Dc. ax. 50° = As. 0 < V. a. = $\frac{20}{20}$
O. U. < R. t. = 12 Ty.

℞ for Dist. and Rd. for Mr. H. R. L.
R. + 1½ Ds. ⊃ + ½ Dc. ax. 150°
L. + 1¾ Ds. ⊃ + ½ Dc. ax. 50°

Patient being only 30 the same pair does for both reading and distance.

*No. 2.*— Mr. D. M. F., aged 35. Says he is "very near-sighted" and wants glasses for the street and for work.

$$\text{N. v.} \begin{cases} \text{R. E.} < \text{D. t.} = \frac{20}{100} < \text{As.} = 170^\circ < \text{R. t.} = 15 \text{ Ty.} \\ \text{L. E.} < \text{D. t.} = \frac{20}{200} < \text{As.} = 15^\circ < \text{R. t.} = 15 \text{ Ty.} \end{cases}$$

$$\text{Tl.} \begin{cases} \text{R. E.} - 3\tfrac{1}{2} \text{ Ds.} = \frac{20}{40} < \text{As.} = 170^\circ > \\ \quad < \frown - 1\tfrac{1}{2} \text{ Dc. ax. } 170^\circ = \text{As. } 0 \\ \quad < \text{V. a.} = \frac{20}{20} \\ \text{L. E.} - 6 \text{ Ds.} = \frac{20}{50} < \text{As.} = 15^\circ > \\ \quad < \frown - 2\tfrac{1}{2} \text{ Dc. ax. } 15^\circ = \text{As. } 0 \\ \quad < \text{V. a.} = \frac{20}{20} \end{cases}$$

℞ for Dist. for Mr. D. M. F.

R. E. — $3\frac{1}{2}$ Ds. $\frown$ — $1\frac{1}{2}$ Dc. ax. $170^\circ$

L. E. — 6 Ds. $\frown$ — $2\frac{1}{2}$. Dc. ax. $15^\circ$

℞ for Rd. for Mr. D M. F.

R. E. — $1\frac{1}{2}$ Ds. $\frown$ — $1\frac{1}{2}$. Dc. ax. $170^\circ$

L. E. — 4 Ds. $\frown$ — $2\frac{1}{2}$ Dc. ax. $15^\circ$

## Examples in Strabismus.

*No. 1.*— Mr. A. E. S., aged 18. Right side of face paralyzed six months ago; constitutional and local treatment ineffective.

$$\text{R. E.} < \text{V. a.} = \frac{20}{20} < \text{Am.} = 0.$$

$$\text{L. E.} < \text{V. a.} = \frac{20}{20} < \text{Am.} = 0.$$

When looking at an object with both eyes it appears double, one above the other. When R. E. is covered L. E. remains fixed; when L. E. is covered R. E. turns downward to natural position. A $12^\circ$ prism, base up, placed before R. E., restores normal binocular vision. It does so because it enables both eyes to fix upon the same

object at the same time. Two prisms of half the strength properly adjusted before the two eyes, accomplish the same result, securing binocular fixation.

℞ for Dist. and Rd. for Mr. A. E. S.
R. E. 6° prism, base *up*.
L. E. 6° prism base *down*.

*No. 2.*— Mr. D. L. H., aged 22. Left eye turns slightly outward, causing diplopia.

R. E. < V. a. $= \frac{20}{20}$ < Am. = 0
L. E. < V. a. $= \frac{20}{20}$ < Am. = 0

Objects appear double, the one seen by the L. E. several inches to the left of the real object as seen by the R. E. When the R. E. is covered the L. E. rotates to normal position. A 7° prism, base out, before L. E., restores normal binocular vision.

℞ for Dist. and Rd. for Mr. D. L. H.
R. E. 3° prism base *out*.
L. E. 4° prism base *out*.

*No. 3.*— Miss B. C. F., aged 19. Convergent strabismus of both eyes, for past 10 years, for distance only. Object seen by R. E. appears to the left of object seen by L. E., and *vice versa*, vision being crossed.

O. D. < V. a. $= \frac{20}{20}$ < Am. = 0.
O. S. < V. a. $= \frac{20}{20}$ < Am. = 0.

A 10° prism, base *in*, before either eye restores normal vision.

℞ for Dist. and Rd. for Miss B. C. F.
O. D. 5° prism base *in*.
O. S. 5° prism base *in*.

Exceptions to the rule illustrated above in tests of As. will be met where the trial will show that the axis of the cylinder should not be set exactly at right angles to the blackest line, as shown in N. v., bringing it parallel to the line most blurred. The blackest line in the N. v. test and in the Tl. test will not be identical. Illustrating exceptions would be more likely to mislead than to help. The examiner must be prepared for variations, and cultivate the temper necessary to master them. During his trial he may find the blackest line shifted exactly to a right angle to the position as shown in the N. v. This will not indicate any exception, but simply an over-correction of the blackest line and a full or approximate correction of the blurred lines as they appeared in the N. v.

It is unnecessary to give strabismal examples fitted with prisms combined with spherical or cylindrical lenses, although this is the most frequent form required. Combinations of lenses are sufficiently illustrated under compound astigmatism. Examples where there is nothing but strabismus are better suited to illustrate the correction of that defect.

No examples of asthenopia are needed. Being the result of various mal-conditions, as previously explained, its correction is various, consisting generally of fitting the eyes properly, resting them, and restoring the system to normal health. Often the asthenopic person, especially if young or under forty, will be found to require simply a pair of weak spherical convex lenses for reading, called by some rest-glasses.

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